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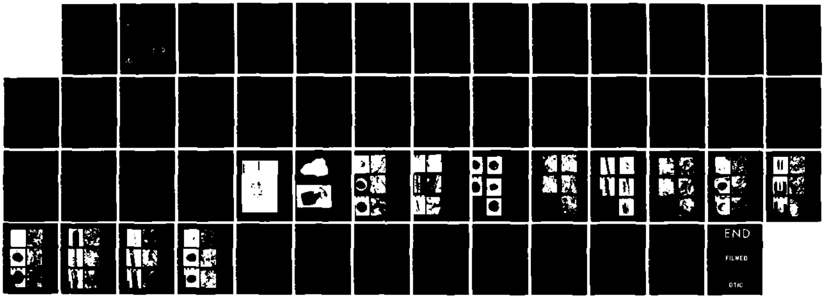

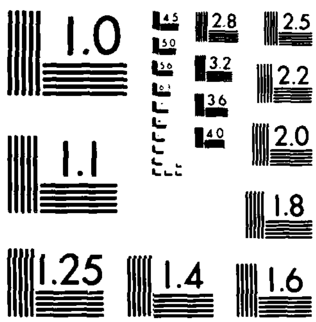

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CHEMICAL AND PHOTOGRAPHIC EVALUATION OF RIGID EXPLOSIVE TRANSFER LINES

BY ELEONORE G. KAYSER

RESEARCH AND TECHNOLOGY DEPARTMENT

MAY 1984

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EXPLOSIVE TRANSFER LINE	SHIELDED MILD DETONATING CORD

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→ This paper describes the chemical and photographic analyses performed on 112 explosive transfer lines used to initiate aircraft emergency escape systems for a variety of military and NASA aircraft. The purpose was to provide quantitative chemical data on in-service explosive transfer lines as affected by both age and heat treatment. These data are necessary in order to make reliable, responsible, and conservative estimations of in-service cord life extension. The approach was to (a) develop a test methodology, (b) characterize the types of transfer lines in use in this country,

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(c) analyze these lines following a repeat of the thermal tests conducted in the original qualification, and (d) conduct a degradation investigation on the explosives currently in use. The results of this testing indicate that rigid explosive transfer lines are not adversely affected by age, service, or a repeat of the thermal qualification tests.

FOREWORD

This report contains the analytical results generated on HNS and DIPAM removed from explosive transfer lines. The chemical and photographic techniques described in this report are part of a joint service life evaluation program funded by the Army Aviation Systems Command (AVSCOM), St. Louis, Missouri, the U.S. Air Force B-1 Program, and the National Aeronautics and Space Administration (NASA) under NASA Defense Purchase Request No. L-9492B. This program was managed at the NASA Langley Research Center, Hampton, Virginia.

The identification of commercial materials and/or manufacturers implies neither criticism nor endorsement by the Naval Surface Weapons Center.

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CONTENTS

	Page
INTRODUCTION	1
EXPERIMENTAL	5
TECHNICAL APPROACH	5
LINES TESTED	6
TESTING SEQUENCE	6
EXPLOSIVE MATERIALS	6
BOOSTER TIP SAMPLING	6
TRANSFER LINE SAMPLING	11
HPLC CONDITIONS	11
COLOR MACROPHOTOGRAPHY	11
SCANNING ELECTRON MICROSCOPY (SEM)	11
RESULTS AND DISCUSSION	13
CONCLUSIONS	37
REFERENCES	38
NOMENCLATURE	39

ILLUSTRATIONS

Figure		Page
1	CROSS SECTION OF RIGID EXPLOSIVE TRANSFER LINE (1 GRAIN = 65 mg)	3
2	TEMPERATURE/TIME CYCLES (100 EACH) REQUIRED FOR THERMAL QUALIFICATION OF RIGID EXPLOSIVE TRANSFER LINES	7
3	CHEMICAL STRUCTURES AND MEETING POINTS OF EXPLOSIVES IN RIGID EXPLOSIVE TRANSFER LINES	9
4	DISSECTION SITES USED FOR PHOTOGRAPHIC AND CHEMICAL ANALYSES	10
5	HPLC CHROMATOGRAM OF HNS, HNBiB, AND DIPAM	12
6	INTERNAL END VIEW OF A BOOSTER TIP REMOVED FROM A TRANSFER LINE EXPOSED TO 425°F FOR 50 HR. PERCENTAGES ARE EXPLOSIVE REMAINING BY WEIGHT	23
7	SIDE VIEW OF FERRULE CHARGE REMOVED FROM A TRANSFER LINE EXPOSED TO 500°F FOR 50 HRS	24
8	SIDE VIEW OF FERRULE CHARGE REMOVED FROM A TRANSFER LINE EXPOSED TO 425°F FOR 50 HRS	24
9	PHOTOGRAPHIC ANALYSES OF AH-1S BOOSTER TIP EXPLOSIVE	25
10	PHOTOGRAPHIC ANALYSES OF AH-1S TRANSFER LINE EXPLOSIVE	26
11	COLOR MACROPHOTOGRAPHS OF AH-1G BOOSTER TIP EXPLOSIVE; ALL LINES ARE 9 YEARS OLD	27
12	SCANNING ELECTRON MICROGRAPHS OF AH-1G BOOSTER TIP EXPLOSIVE; ALL LINES ARE 9 YEARS OLD	28
13	COLOR MACROPHOTOGRAPHS OF AH-1G TRANSFER LINE EXPLOSIVE; ALL LINES ARE 9 YEARS OLD	29
14	SCANNING ELECTRON MICROGRAPHS OF AH-1G TRANSFER LINE EXPLOSIVE; ALL LINES ARE 9 YEARS OLD	30

ILLUSTRATIONS (CONT.)

Figure		Page
15	PHOTOGRAPHIC ANALYSES OF F-14 BOOSTER TIP EXPLOSIVE	31
16	PHOTOGRAPHIC ANALYSES OF F-14 TRANSFER LINE EXPLOSIVE	32
17	PHOTOGRAPHIC ANALYSES OF B-1 BOOSTER TIP EXPLOSIVE	33
18	PHOTOGRAPHIC ANALYSES OF B-1 TRANSFER LINE EXPLOSIVE	34
19	PHOTOGRAPHIC ANALYSES OF F-111 TRANSFER LINE EXPLOSIVE	35
20	PHOTOGRAPHIC ANALYSES OF F-111 BOOSTER TIP EXPLOSIVE	36

TABLES

Table		Page
1	NUMBER OF LINES AND RATED SERVICE LIFE OF VARIOUS AIRCRAFT	2
2	TYPES OF SMDC LINES CURRENTLY IN USE	4
3	EXPLOSIVE TRANSFER LINES TESTED	8
4	CHEMICAL ANALYSES OF RIGID EXPLOSIVE TRANSFER LINES INSTALLED ON THE F-111 AIRCRAFT AFTER 4 YEARS OF SERVICE	14
5	CHEMICAL ANALYSES OF RIGID EXPLOSIVE TRANSFER LINES INSTALLED ON THE AH-1G AIRCRAFT AFTER 7 YEARS OF SERVICE	15
6	CHEMICAL ANALYSES OF RIGID EXPLOSIVE TRANSFER LINES INSTALLED ON THE AH-1S AIRCRAFT AFTER 4.7 YEARS OF SERVICE	17
7	CHEMICAL ANALYSES OF RIGID EXPLOSIVE TRANSFER LINES INSTALLED ON THE F-15 AIRCRAFT AFTER 6 YEARS OF SERVICE	18
8	CHEMICAL ANALYSES OF RIGID EXPLOSIVE TRANSFER LINES INSTALLED ON THE B-1 AIRCRAFT AFTER 3 YEARS OF SERVICE	19
9	CHEMICAL ANALYSES OF RIGID EXPLOSIVE TRANSFER LINES INSTALLED ON THE F-14 AIRCRAFT AFTER 3 YEARS OF SERVICE	20
10	EFFECT OF HEAT ON CHEMICAL COMPOSITION	21
11	CHEMICAL ANALYSIS OF EXPLOSIVE TRANSFER LINES	22

INTRODUCTION

Extending the service life of explosive transfer lines, used to initiate and sequence aircraft emergency crew escape systems, provides an opportunity for significant savings[1] for a wide variety of military and NASA aircraft (see Table 1). Previous surveillance programs[2] have relied on methods which provided limited information on the functional status of transfer lines having full service, and the projection of further service extension. The purpose of the effort described in this report is to provide quantitative information on explosive transfer lines which will contribute to responsible, conservative, service life determinations.

Rigid explosive transfer lines (Figure 1), commonly called shielded mild detonating cord (SMDC), are designed to transfer a fully contained explosive stimulus, and are the most extensively applied components in aircraft crew escape systems. These lines utilize small quantities of highly stable explosives (i.e., 2,2',4,4',6,6'-hexanitrostilbene (HNS)[3] and dipicramide (DIPAM)[4]) in a metal sheath (i.e., silver or aluminum). SMDC lines are normally used to interconnect the components of emergency escape functions. More than one million cords have been manufactured for various aircraft, spacecraft, and missiles, which include the Army AH-1, the NASA/Army Rotor Systems Research Aircraft (RSRA), the NASA Space Shuttle,[5] the Air Force F-111,[6] F-15, F-16, and B-1, and the Navy TA-7, S-3A, F-14, and F-18. To date, this program has evaluated transfer lines from the following aircraft: the Army AH-1G, and AH-1S, the Air Force F-111, F-15, and B-1, and the Navy F-14. Each of the lines used in these aircraft is different from the others in terms of materials and manufacturing processes and represents all of the rigid transfer line types in use in this country (see Table 2).

The establishment of a rated service life for these lines has been approached on a conservative basis, due to the life-critical function that they perform. A relatively short service life, from three to five years for most aircraft systems, was originally established. Until recently, little interchange of service life technology has occurred among the various aircraft surveillance programs. The chemical and photographic techniques described in this report are part of a joint Army, Air Force, NASA, explosive transfer line service life extension program.[7]

More than 800 rigid explosive transfer lines[7] have been evaluated. Lines were removed after full service from the Army AH-1G and AH-1S, the Air Force F-111, B-1, and F-15 and the Navy F14 aircraft. Seven year-old B-1 lines with no service were also evaluated. These lines represent the three explosive cord types (1) silver-sheathed HNS-II, (2) aluminum-sheathed HNS-II, and (3) silver-sheathed DIPAM currently in use. The three manufacturing methods used to

TABLE 1. NUMBER OF LINES AND RATED SERVICE LIFE OF VARIOUS AIRCRAFT

AIRCRAFT	NO. OF LINES/AIRCRAFT	SERVICE LIFE IN YEARS INITIAL	SERVICE LIFE IN YEARS CURRENT (as of May 84)
AH-1G*	13	5	on condition
AH-1S*	16	5	on condition
B-1 (capsule)	1200	3	13
B-1B	504	3	15
F-111	258	1.5	15
F-14	156	3	5
F-15 (fighter)	22	6	15
F-15 (trainer)	68	6	15
F-16	27	15	15
F-18 (fighter)	13	5	5
F-18 (trainer)	52	5	5
RSRA	145	5	on condition

*Projected savings of $9M with extension to 10 years.[1]

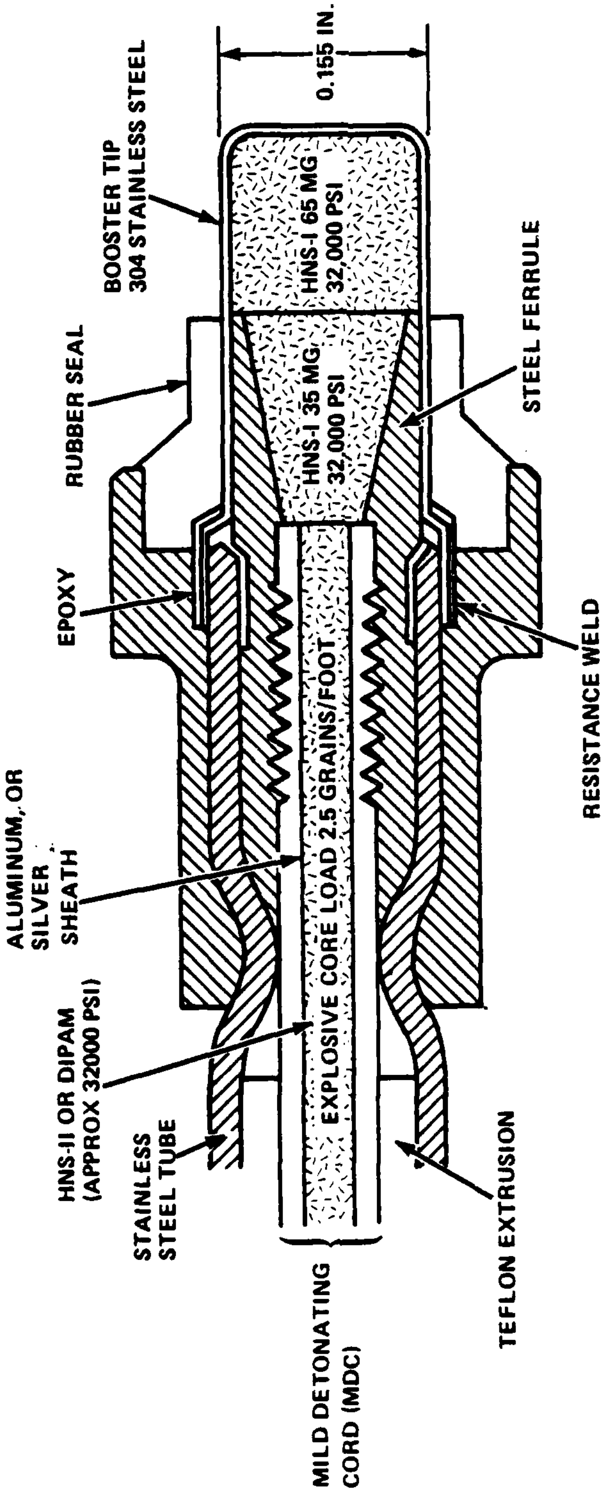


FIGURE 1. CROSS SECTION OF RIGID EXPLOSIVE TRANSFER LINE (1 GRAIN = 65 MG)

TABLE 2. TYPES OF SMDC LINES CURRENTLY IN USE

SMDC LINES	AIRCRAFT/SPACECRAFT/MISSILE
HNS-II	
(silver sheathed)	AH-1
" "	EA-6
" "	F-14
" "	F-16
" "	F-18
" "	RSRA
" "	S-3A
" "	Harpoon Missile
" "	Delta Launch Vehicle
HNS-II	
(aluminum sheathed)	B-1
" "	Trident Missile
DIPAM	
(silver sheathed)	F-111
" "	F-15

fabricate these cords are: (1) swage-hammering of fully annealed tubes, (2) swage-hammering of work-hardened tubes using three 425°F/one-hour annealing cycles, and (3) pultrusion (see Nomenclature).

The overall objectives of this program[7] were:

1. to develop a chemical and functional test methodology, and establish standards for comparison to all subsequent samples;

2. to determine chemical and functional reproducibility among line types, manufacturing methods, and batches;

3. to determine effects of age and service on the oldest available lines;

4. to evaluate lines with rated service which have undergone a repeat thermal qualification test;

5. to conduct thermal degradation studies to determine the limits at which line functionality can be maintained; and

6. to establish degradation limits and mechanisms for the energetic materials HNS and DIPAM.

The chemical[5,7,8] and photographic[7] analyses (color macrophotographs and scanning electron microphotographs (SEM's)) were developed and carried out at the Naval Surface Weapons Center-White Oak, while the functional tests (velocity and energy measurements) as well as the nondestructive tests were (helium leak detection and X-ray photography) were developed and performed at the NASA Langley Research Center. The results of all these tests can be found in reference 7.

EXPERIMENTAL

TECHNICAL APPROACH

The technical approach included the five following test objectives:

1. Establish chemical standards against which all subsequent test groups would be compared. The most recently manufactured lines with the least service were used to establish this baseline. New lines with no history of service would have provided the best reference standards. However, only new AH-1S aircraft lines were available.

2. Determine the effects of age (shelf life) without service. The only components available for this study were the spares for the B-1 aircraft system qualification with a storage life of 7 to 8 years.

3. Evaluate the effects of rated, installed service time (service life) on lines from each aircraft. The oldest age-with-service group was used for this evaluation with the exception of the AH-1G where the service life demonstration

was omitted. Thermal qualification tests including 72-hour exposure at -110°F to +200°F for the Army AH-1G and AH-1S as well as the thermal parameters detailed in Figure 2 were repeated on full service lines to provide a credible basis for possible service life extension.

4. Define the chemical and physical changes which occur as the transfer lines degrade.

5. Determine to what extent material degradation can cause functional failure. Since no functional failure due to ambient storage and/or service was observed, degradation was induced by exposure to elevated temperatures. Lines subjected to 50-hour exposures at 375°F, 400°F, 425°F, and 450°F were chemically and photographically analyzed. To investigate even broader degradation limits, lines from the F-111 aircraft were exposed to temperatures up to 600°F. Each line was inventoried in terms of aircraft, service, manufacturer, manufacturing lot, manufacturing process, manufacturing date, part number, and serial number.

LINES TESTED

Data describing the investigated rigid explosive transfer lines can be found in Table 3.

TESTING SEQUENCE

The chemical and photographic analyses were carried out in the following order:

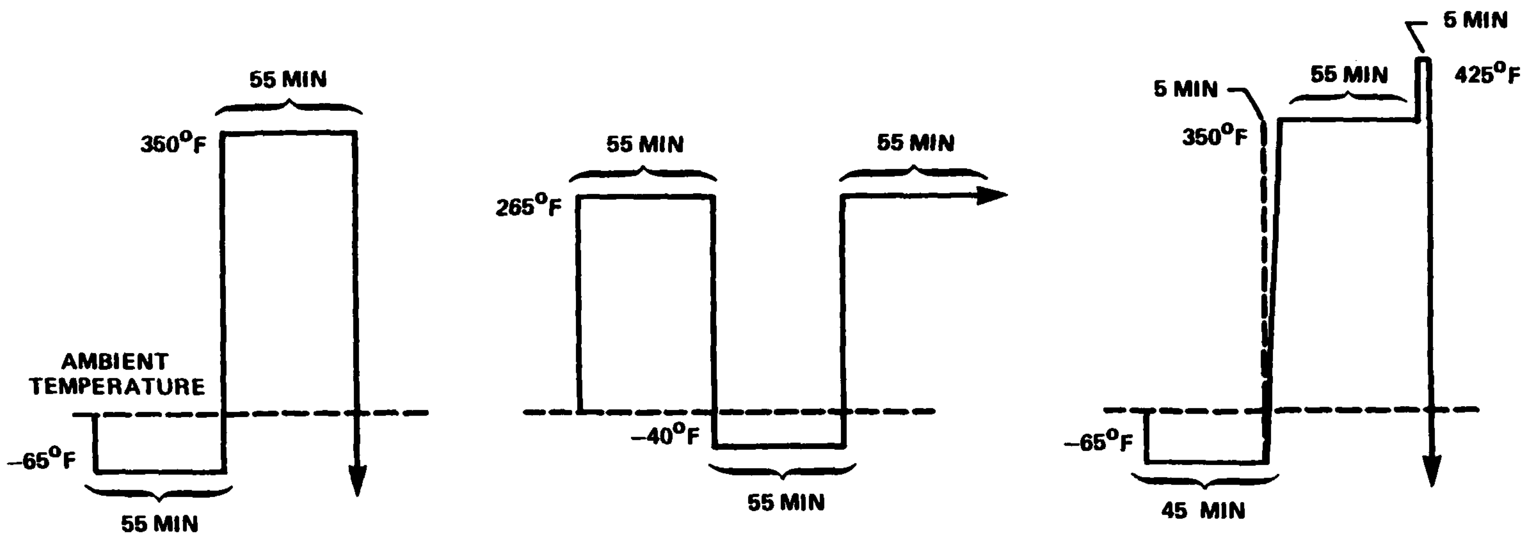
1. Color Macrophotographs
2. SEM
3. HPLC Analyses

EXPLOSIVE MATERIALS

The explosives used in the investigated rigid transfer lines include HNS[9,10,11] (Navy Spec. WS-5003[12]) and DIPAM (Navy Spec. WS-4660[13]). HNS-I, the initial product derived in the synthesis is used in the booster tips due to its sensitivity to low initiation inputs (pressure impulse and fragment impacts), while HNS-II (recrystallized HNS-I) is employed in the transfer lines because of its more desirable flow properties. High purity standards of HNS, DIPAM, and HNBiB (major impurity in HNS synthesis) were prepared to provide a reference calibration for the materials removed from the five aircraft types. The chemical structure and thermal properties of these compounds can be found in Figure 3.

BOOSTER TIP SAMPLING

The booster tip (Figure 4) was dissected with a tube cutter at the ferrule charge-to-booster charge plane. The cup was cut and broken open to minimize any physical disturbance of the pressed explosive. For the HPLC analyses, HNS was



(A) F-14 AIRCRAFT.

(B) B-1 AIRCRAFT.

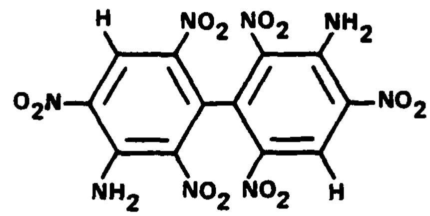
(C) F-111 AIRCRAFT.

FIGURE 2. TEMPERATURE/TIME CYCLES (100 EACH) REQUIRED FOR THERMAL QUALIFICATION OF RIGID EXPLOSIVE TRANSFER LINES

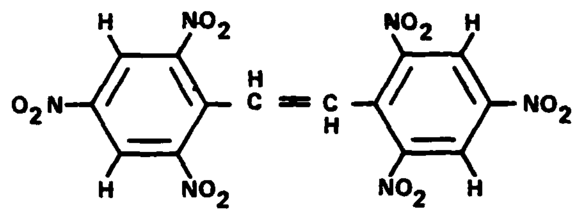
TABLE 3. EXPLOSIVE TRANSFER LINES TESTED

AIRCRAFT	EXPLOSIVE CORE	MDC SHEATH	MANUFACTURING PROCESS (MDC)	MANUFACTURER	INITIAL SERVICE (Years)	NO. OF LINES/ AIRCRAFT	PYRO CHANGE-OUT TIME (Manhours)
AH-1G	HNS-II	silver	swage/hammer, with annealing	Teledyne McCormick-Selph (TMc/S)	5	13	60
AH-1S	HNS-II	silver	pultrusion	Space Ordnance Systems (SOS)	5	16	60
F-14	HNS-II	silver	swage/hammer, no annealing	Explosive Technology (ET)	3	156	500
B-1 (capsule)	HNS-II	aluminum	swage/hammer, with annealing	Teledyne McCormick-Selph (TMc/S)	3	1200	40,000
F-111	DIPAM	silver	swage/hammer, with annealing	Teledyne McCormick-Selph (TMc/S)	1.5	258	
F-15	DIPAM	silver	swage/hammer, no annealing	Explosive Technology (ET)	6	22-68	

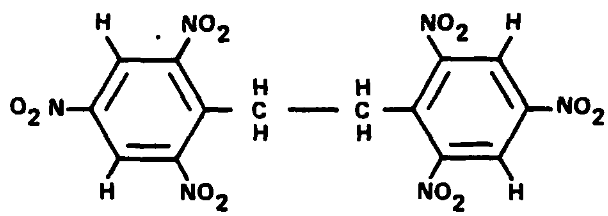
DIPAM
DIPICRAMIDE
MOLECULAR WEIGHT = 454



HNS
2, 2', 4, 4', 6, 6' - HEXANITROSTILBENE
MOLECULAR WEIGHT = 450

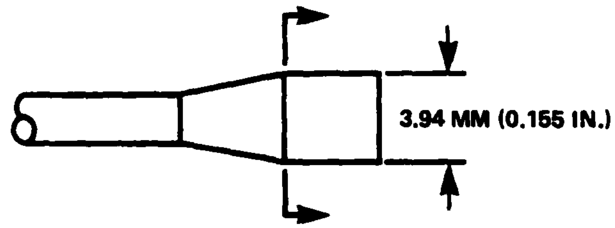


HNBiB
2, 2', 4, 4', 6, 6' - HEXANITROBIBENZYL,
DIPICRYLETHANE
MOLECULAR WEIGHT = 452

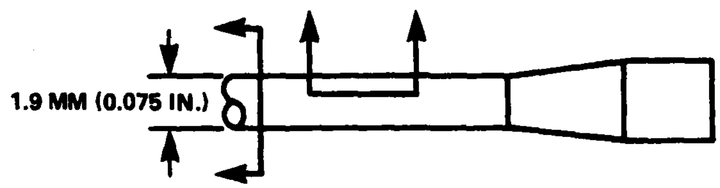


COMPOUND	MELTING POINT
DIPAM	583°F
HNS-I	601°F
HNS-II	604°F
HNBiB	424°F

FIGURE 3. CHEMICAL STRUCTURES AND MELTING POINTS OF EXPLOSIVES IN RIGID EXPLOSIVE TRANSFER LINES



(A) BOOSTER TIP



(B) TRANSFER LINE

FIGURE 4. DISSECTION SITES USED FOR PHOTOGRAPHIC AND CHEMICAL ANALYSES

removed from the cup and the material was mechanically blended. The samples were weighed on a Mettler Microbalance (standard deviation 1.0μgm) and then dissolved in dimethylsulfoxide (DMSO). Two to three HPLC analyses were determined on each booster tip. Additional analyses were obtained whenever changes were observed. The HNS-I booster tip analyses were reproducible to within ±3%.

TRANSFER LINE SAMPLING

The explosive cord (Figure 4) was cut with a tubing cutter approximately 4cm from each end, and at the midpoint if the cord length was greater than 26cm (10 inches). For the HPLC analyses, a 1 to 2mm cross section was cut from the cord. DMSO was added to the Ag or Al sheathed transfer line samples. This solution was placed in an ultrasonic bath at room temperature for approximately 30 minutes to completely dissolve the explosive. The quantity of explosive was determined by the tare in weighing the original and empty cord length. Two or more transfer lines were tested with a minimum of 3 HPLC analyses on each sample. Additional lines and samples were tested whenever changes were observed.

HPLC CONDITIONS

A high performance liquid chromatograph (Waters Associates Model ALC 202) equipped with a 254nm wavelength detector, a solvent delivery system (Model 6000), and a U6K high pressure loop injector was used with a Model RCM-100 module containing a reverse-phase C-18 Radial-Pak cartridge. Sample solutions were eluted isocratically at ambient temperature. Column flow was 2.0ml/minute, with the mobile phase consisting of HPLC grade methanol and distilled water, 50:50(v,v). The solvent mixtures were not degassed prior to HPLC analysis and sample injections of 2 to 20 microliters were used. A typical time plot of the materials[8] used in this study can be found in Figure 5.

COLOR MACROPHOTOGRAPHY

Color photographs (15-25X magnification) were taken of cross sections of the booster tips. In order to expose the core, a 2-inch section was opened longitudinally with a Nicholson flat file. The photographs were obtained with a Polaroid camera and a Wild Microscope lens (M-75, type 352873), made in Herrbrugg, Switzerland - Kodak Vericolor II, type L (4X5) film was used for documentation.

SCANNING ELECTRON MICROSCOPY (SEM)

The SEM photographs were obtained with an AMRAY, Model 1000A, scanning electron microscrope (5000X magnification). The SEM data were processed on a cathode ray tube (7 inch diagonal, 2500 line resolution) and photographed with a Polaroid camera. Sample preparation included vacuum sputter-coating with gold.

ISOCRATIC ELUTION
DETECTOR WAVELENGTH: 254 NM
MOBILE PHASE: METHANOL:WATER (50:50, BY VOLUME)
FLOW RATE: 2.0 ML/MIN
SCALE: 0.05 ABSORBANCE UNITS FULL SCALE
SAMPLE SIZE: 5μl
CHART SPEED: 0.5 CM/MIN
SAMPLE SOLVENT: DMSO
R_t: RETENTION TIME AT MAX. PEAK HEIGHT, MINUTES
T_0: TEST START

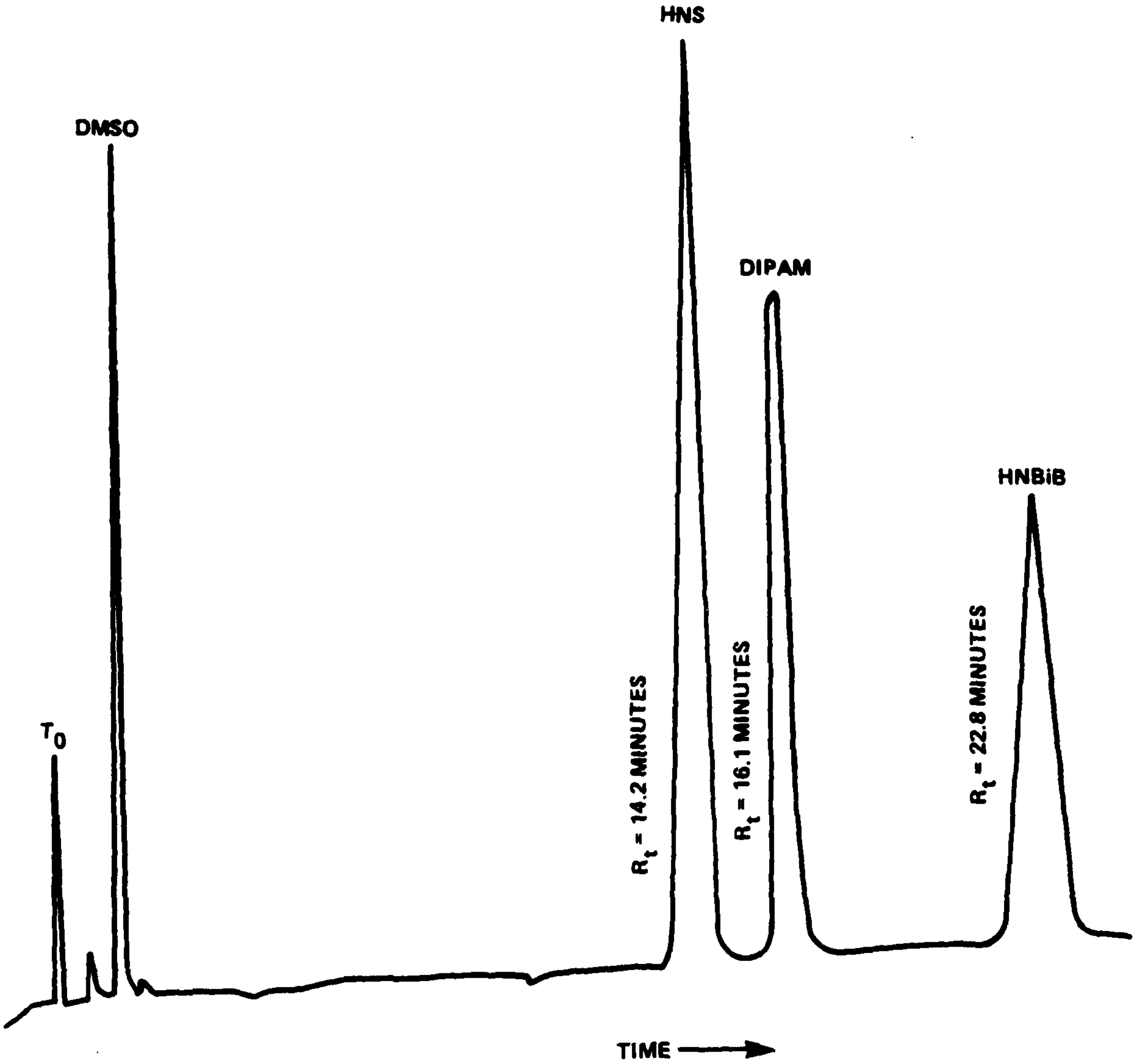


FIGURE 5. HPLC CHROMATOGRAM OF HNS, HNBiB, AND DIPAM

RESULTS AND DISCUSSION

To date, a total of 112 transfer lines have been analyzed chemically and photographically. This evaluation revealed physical and chemical changes in both HNS and DIPAM at elevated temperatures (>375°F/50 hours). Material uniformity was shown to exist among (a) various line manufacturers, (b) several manufacturing methods, (c) line types, and (d) material batches. None of the five aircraft line types exhibited any significant change due to (a) shelf life ranging from 1 to 10 years, (b) service life of 3 to 7 years, (c) rated service with a repeat thermal qualification, or (d) thermal exposure up to and including a 375°F/50 hour heat cycle (see Tables 4 through 11) which is well beyond the temperature requirements (Figure 2) for the above mentioned aircraft.[1]

Material degradation was only noted at high thermal inputs. As expected, the HNBiB (mp 424°F) degraded more rapidly than the HNS (mp 602°F). The weight percent of HNBiB found in the HNS-I of the AH-1G, AH-1S, F-111, and F-14 lines was approximately 2%, and 6% for the B-1, while the percentage of HNBiB in the HNS-II ranged from zero to 2.1 percent. DIPAM exhibited no degradation up to and including the 450°F/50 hour heat cycle. The effects of thermal inputs on DIPAM up to and including 550°F can be seen in Table 10. Essentially, total DIPAM decomposition (94.6%) occurred at 500°F.

HNS-II degradation in the aluminum sheathing was less than that observed in the silver sheathing. This could be due to the lower HNS-II loading density of the aluminum cords. The velocity data[7] obtained from the Ag and Al cords corroborates these results. HNS degradation observed at the high temperatures was also accelerated by the presence of HNBiB. The higher the concentration of HNBiB, the greater the degree of degradation.

As heat-induced degradation occurred in the explosive materials, both color and physical texture changed. The booster tip explosive was found to darken progressively from the outer circumference (Figure 6). Removal and analysis of the darkened material revealed considerably more degradation at the explosive/ stainless steel interface than could be found in the center material. Heat-induced decomposition of the HNS-I contained in the ferrule can be seen in Figures 7 and 8. The percentage of explosive material remaining after exposure to 500°F for 50 hours is shown in Figure 7. The density variations noted in Figure 8 were caused by pressing the explosive into the conical cavity (ferrule). Increased decomposition was observed where HNS compaction was the highest (lowest density at the left - Figure 8).

Color macrophotographs and scanning electron micrographs provided qualitative corroboration for the chemical analyses by high performance liquid chromatography. The results of these chemical and photographic analyses were also corroborated by actual functional tests as described in reference 7. The color macrophotographs show a darkening of the explosive material with increased thermal inputs (Figures 9-11, 13, 15-20). SEM photographs (Figures 9, 10, 12, 14-20) indicate a gradual roughening of the particles, as degradation increased, leading finally to a perforated "swiss cheese"-like texture.

TABLE 4. CHEMICAL ANALYSES OF RIGID EXPLOSIVE TRANSFER LINES INSTALLED ON THE F-111 AIRCRAFT AFTER 4 YEARS OF SERVICE

LINE MANUFACTURER - TMc/S
TEST PERIOD 4/81 - 9/82

TEST GROUP	TEST PARAMETERS	MFG. DATE	BOOSTER TIP WT. % HNS-I	BOOSTER TIP WT. % HNBiB	TRANSFER LINE WT. % DIPAM	LOT NO.	SERIAL NO.
PS	as received	1/75	96.7±0.6	3.8±0.2	97.4±1.0	MSV 8555-5	37304895
PS	as received	1/75	96.3±0.4	3.4±0.0	97.4±0.2	MSV 8555-5	28200253
PS	as received	1/75	98.2±1.3	3.6±0.1	100.0±2.0	MSV 8555-5	36504503
PS	as received	6/72	99.7±0.4	1.5±0.1	99.3±0.3	MSV 8553-10	49349468
SLD	as received	5/72	97.0±0.2	2.1±0.3	101.9±2.0	MSV 8553-5	39339383
SLD	as received	5/72	98.1±0.3	2.1±0.1	96.4±2.0	MSV 8553-5	39439457
SLD	as received	6/72	98.1±1.0	2.0±0.2	98.2±1.0	MSV 8553-10	45949091
SLD	as received	6/72	97.2±0.1	1.9±0.1	96.9±0.1	MSV 8553-10	64349649
SLD	as received	6/72	98.1±0.0	1.8±0.0	98.0±0.9	MSV 8553-10	64449675
SLD	as received	6/72	95.1±1.0	3.6±0.2	98.0±0.5	MSV 8553-10	46049150
RTQ	Figure 2	6/72	98.0±1.5	1.8±0.2	98.3±0.5	MSV 8553-9	09646449
RTQ	Figure 2	6/72	97.4±1.3	1.7±0.2	98.9±0.1	MSV 8553-9	09646527
DI	400°F/50 hrs	1/75	93.1±1.1	2.5±0.2	101.1±0.3	MSV 8555-5	49308638
DI	400°F/50 hrs	1/75	88.9±1.2	2.1±0.1	96.9±1.5	MSV 8555-5	26199420
DI	425°F/50 hrs	1/75	75.3±0.8	1.4±0.1	100.0±2.3	MSV 8555-5	65702369
DI	425°F/50 hrs	1/76	82.9±1.3	1.4±0.2	96.6±1.5	MSV 8555-5	65702418
DI	450°F/50 hrs	1/75	71.9±2.9	0.8±0.0	100.0±3.2	MSV 8555-5	63401029
DI	450°F/50 hrs	1/75	65.5±1.1	0.8±0.0	100.8±2.2	MSV 8555-6	26414524
DI	500°F/50 hrs	2/75	8.6±1.5		*	MSV 8555-4	P/N 1609
DI	500°F/50 hrs	11/74	32.7±3.2		8.3±0.0	MSV 8555-4	40289904
DI	500°F/50 hrs	11/74	23.7±3.7		8.1±0.0	MSV 8555-3	25988189
DI	550°F/50 hrs	10/74	*		*	MSV 8555-3	25493359
DI	550°F/50 hrs	10/74	0.3±1.3		<0.1	MSV 8555-3	25493359
DI	550°F/50 hrs	10/74	*		*	MSV 8555-3	26288244
DI	600°F/50 hrs	10/74	0.9±3.7		*	MSV 8555-3	24993152
DI	600°F/50 hrs	10/74	0.4±3.5		*	MSV 8555-3	24492992
DI	600°F/50 hrs	10/74	*		*	MSV 8555-3	09692597

*Both booster tips were burst by internal pressure, transfer line was empty

TABLE 5. CHEMICAL ANALYSES OF RIGID EXPLOSIVE TRANSFER LINES INSTALLED ON THE AH-1G AIRCRAFT AFTER 7 YEARS OF SERVICE

LINE MANUFACTURER - TMc/S
TEST PERIOD 2/81 - 5/82

TEST GROUP	TEST PARAMETERS	MFG. DATE	BOOSTER TIP WT.% HNS-I	BOOSTER TIP WT.% HNBiB	TRANSFER LINE WT.% HNS-II	TRANSFER LINE WT.% HNBiB	LOT NO.	SERIAL NO.
PS	as recieved	2/77	93.4±0.1	5.5±0.2	100.0±0.5	0.0	7967-1	1523
PS	as received	7/72	98.7±0.2	1.7±0.1	95.4±1.5	1.1±0.0	7180-9	443
PS	as received	2/77	93.0±0.1	5.2±0.2	94.2±0.2	0.0	7967-1	1546
RTQ	-110°F/72 hrs	9/72	98.9±0.9	1.3±0.2	96.4±0.5	2.0±0.2	7180-13	970
RTQ	-110°F/72 hrs	9/72	94.5±0.0	1.7±0.1	93.9±0.4	1.3±0.0	7180-13	983
RTQ	-110°F/72 hrs	7/72	92.3±0.8	1.6±0.3	92.2±0.1	0.0	7180-9	665
RTQ	-110°F/72 hrs	7/72	93.9±0.3	2.5±0.1	95.6±0.5	0.4±0.2	7180-9	650
RTQ	+200°F/72 hrs	4/72	90.2±0.3	5.5±0.5	94.4±0.5	0.0	7180-2	229
RTQ	+200°F/72 hrs	5/72	93.8±0.7	2.0±0.2	93.9±0.4	0.7±0.2	7180-3	252
RTQ	+200°F/72 hrs	7/72	96.0±0.3	1.7±0.2	96.5±0.3	0.9±0.2	7180-9	531
RTQ	+200°F/72 hrs	5/72	99.0±0.4	2.0±0.5	94.9±0.3	1.1±0.3	7180-3	238
RTQ	+200°F/72 hrs	6/72	96.8±1.0	1.9±0.1	95.6±0.0	1.0±0.0	7180-9	330
RTQ	+200°F/72 hrs	6/72	94.6±0.1	1.8±0.1	94.5±0.2	0.9±1.0	7180-7	342
DI	375°F/50 hrs	2/77	92.7±0.5	4.2±0.2	96.9±1.5	0.0	7967-1	1562
DI	375°F/50 hrs	2/77	92.4±1.0	4.1±0.1	97.6±3.3	0.0	7967-1	1645
DI	400°F/50 hrs	7/72	93.4±0.2	1.8±0.2	51.4±3.7	0.0	7180-9	531
DI	400°F/50 hrs	5/72	92.2±1.8	2.0±0.0	89.9±2.0	0.0	7180-3	238
DI	400°F/50 hrs	10/73	90.7±0.5	1.4±0.2	87.8±1.0	0.7±0.3	7452-3	1216
DI	400°F/50 hrs	9/72	91.6±0.4	1.6±0.2	71.0±2.0	0.9±0.4	7180-13	1051
DI	400°F/50 hrs	8/72	91.4±0.9	2.0±0.2	66.6±5.0	0.0	•7180-12	791
DI	400°F/50 hrs	7/72	91.4±0.9	1.3±0.1	51.7±4.8	0.0	7180-9	545
DI	425°F/50 hrs	8/72	88.5±2.6	1.1±0.1	11.5±1.4	0.0	7180-12	800
DI	425°F/50 hrs	8/72	93.1±1.5	1.3±0.1	53.6±0.9	0.0	7180-11	858
DI	425°F/50 hrs	8/72	88.4±0.8	1.2±0.1	42.1±2.1	0.0	7180-11	884
DI	425°F/50 hrs	8/72	93.4±2.9	1.1±0.5	6.0±1.2	0.0	7180-11	716
DI	425°F/50 hrs	8/72	88.3±0.3	0.9±0.0	43.3±0.7	0.0	7180-11	894
DI	425°F/50 hrs	8/72	93.9±0.7	0.9±0.0	41.4±0.2	0.0	7180-12	901
DI	425°F/50 hrs	8/72	93.5±1.8	0.9±0.1	0.0	0.0	7180-12	927
DI	425°F/50 hrs	8/72	93.6±1.9	1.2±0.3	37.9±5.2	0.0	7180-12	921
DI	425°F/50 hrs	9/72	90.4±0.1	1.0±0.0	44.0±2.9	0.0	7180-13	894

TABLE 5. (Cont.)

TEST GROUP	TEST PARAMETERS	MFG. DATE	BOOSTER TIP WT.% HNS-I	BOOSTER TIP WT.% HNBiB	TRANSFER LINE WT.% HNS-II	TRANSFER LINE WT.% HNBiB	LOT NO.	SERIAL NO.
DI	425°F/50 hrs	7/72	91.4±0.9	0.7±0.1	11.1±0.8	0.0	7180-9	549
DI	425°F/50 hrs	9/72	91.3±1.0	1.7±0.2	47.1±1.0	0.0	7180-13	939
DI	425°F/50 hrs	7/72	84.7±2.0	0.7±0.1	0.0	0.0	7180-9	544
DI	425°F/50 hrs	6/72	89.6±0.5	1.3±0.1	2.9±0.4	0.0	7180-7	441
DI	425°F/50 hrs	8/72	90.1±2.0	1.5±0.1	7.0±0.5	0.0	7180-12	904
DI	425°F/50 hrs	7/72	90.5±1.0	1.4±0.2	0.0	0.0	7180-9	576

TABLE 6. CHEMICAL ANALYSES OF RIGID EXPLOSIVE TRANSFER LINES INSTALLED ON THE AH-1S AIRCRAFT AFTER 4.7 YEARS OF SERVICE

LINE MANUFACTURER - SOS
TEST PERIOD 7/82 - 11/82

TEST GROUP	TEST PARAMETERS	MFG. DATE	BOOSTER TIP WT.% HNS-I	BOOSTER TIP WT.% HNBiB	TRANSFER LINE WT.% HNS-II	TRANSFER LINE WT.% HNBiB	LOT NO.	SERIAL NO.
PS	as received	7/77	96.0±1.0	3.6±0.8	97.5±0.5	0.0	SNF5	897
PS	as received	7/77	98.0±0.5	2.0±0.2	96.5±0.0	0.0	SNF4	322
SLD	as received	2/78	96.0±1.5	2.9±0.8	98.5±1.0	0.1±0.0	SNE14	1724
SLD	as received	2/78	96.4±1.2	3.4±0.4	98.6±1.6	0.2±0.1	SNE14	1684
RTQ	-110°F/72 hrs	2/78	95.0±0.8	3.2±0.5	99.6±1.5	0.2±0.2	SNE14	1710
RTQ	-110°F/72 hrs	2/78	98.0±1.3	3.4±0.2	98.3±1.0	0.1±0.0	SNE14	1699
RTQ	+200°F/72 hrs	2/78	97.0±1.2	3.4±0.5	96.8±0.8	0.[illegible]±0.1	SNE14	1681
RTQ	+200°F/72 hrs	2/78	97.9±0.6	3.4±0.6	96.4±0.9	0.1±0.1	SNE14	1693
DI	375°F/50 hrs	12/79	96.1±1.0	2.3±0.2	100.5±0.2	0.0	TAE11	4157
DI	375°F/50 hrs	12/79	96.4±1.0	1.3±0.1	99.2±1.2	0.0	TAE11	4156
DI	400°F/50 hrs	7/77	91.7±0.1	3.5±0.2	86.1±2.0	0.5±0.1	SNE4	797
DI	400°F/50 hrs	7/77	88.7±0.2	2.6±0.0	89.1±0.7	0.0	SNE4	813

TABLE 7. CHEMICAL ANALYSES OF RIGID EXPLOSIVE TRANSFER LINES INSTALLED ON THE F-15 AIRCRAFT AFTER 6 YEARS OF SERVICE

LINE MANUFACTURER - ET
TEST PERIOD 10/82 - 2/83

TEST GROUP	TEST PARAMETERS	MFG. DATE	BOOSTER TIP WT. % HNS-I	BOOSTER TIP WT. % HNBiB	TRANSFER LINE DIPAM	LOT NO.	SERIAL NO.
SLD	6 years of service	4/74	100.0±3.0	0.5±0.0	98.0±2.5	ETI-1-6	0373
SLD	6 years of service	4/74	98.0±2.5	0.5±0.2	97.1±1.0	ETI-1-6	0373
SLD	6 years of service	4/74	97.2±1.0	1.0±0.1	94.5±1.0	ETI-1-6	0373

TABLE 8. CHEMICAL ANALYSES OF RIGID EXPLOSIVE TRANSFER LINES INSTALLED ON THE B-1 AIRCRAFT AFTER 3 YEARS OF SERVICE

LINE MANUFACTURER - TMc/S
TEST PERIOD 5/81 - 4/82

TEST GROUP	TEST PARAMETERS	MFG. DATE	BOOSTER TIP WT.% HNS-I	BOOSTER TIP WT.% HNBiB	TRANSFER LINE WT.% HNS-II	TRANSFER LINE WT.% HNBiB	LOT NO.	SERIAL NO.
PS	as received	3/77	94.0±0.6	4.9±0.0	97.0±0.5	0.0	7886-21	10434
PS	as received	7/73	92.8±0.2	6.0±0.2	97.9±0.4	0.0	7060-269	43717
SL	as received	6/73	90.8±0.4	6.3±0.3	93.3±0.4	1.5±0.2		74225
SL	as received	4/73	90.4±0.2	6.6±0.4	95.4±0.5	1.2±0.1	7060-213	74201
DI	375°F/50 hrs	3/77	96.4±0.2	4.4±2.0	99.8±0.1	0.0	7886-21	10400
DI	375°F/50 hrs	3/77	92.3±0.1	5.2±0.1	100.2±1.9	0.0	7886-21	10403
DI	400°F/50 hrs	3/77	89.6±0.2	5.0±0.2	93.8±0.3	0.0	7886-21	10577
DI	400°F/50 hrs	3/77	90.1±0.1	5.1±0.2	93.1±1.0	0.0	7886-21	10578
DI	425°F/50 hrs	3/77	85.9±0.6	3.3±0.2	85.4±0.5	0.0	7886-21	10513
DI	425°F/50 hrs	3/77	87.5±0.5	3.2±0.3	91.3±0.1	0.0	7886-21	10512
RTQ	Figure 2	7/73	88.2±2.0	5.8±0.2	94.3±0.0	2.0±0.1	7060-275	82102
RTQ	Figure 2	7/73	89.5±0.5	6.7±0.2	94.0±0.8	2.1±0.2	7060-274	34253
RTQ	Figure 2	4/73	89.3±0.3	5.6±0.2	94.7±0.0	0.7±0.2	7060-216	34190

TABLE 9. CHEMICAL ANALYSES OF RIGID EXPLOSIVE TRANSFER LINES INSTALLED ON THE F-14 AIRCRAFT AFTER 3 YEARS OF SERVICE

LINE MANUFACTURER - ET
TEST PERIOD 12/81 - 3/83

TEST GROUP	TEST PARAMETERS	MFG. DATE	BOOSTER TIP WT.% HNS-I	BOOSTER TIP WT.% HNBiB	TRANSFER LINE WT.% HNS-II	TRANSFER LINE WT.% HNBiB	LOT NO.	SERIAL NO.
PS	as received	2/75	97.8±0.1	0.8±0.1	100.0±0.0	0.0	4-ETI-0275	3380-12
PS	as received	2/75	99.4±0.2	0.8±0.1	100.0±0.1	0.0	4-ETI-0275	3380-2
SLD	as received	2/72	95.8±0.1	3.8±1.6	99.8±0.0	0.0	3002-79	43
SLD	as received	2/72	96.6±0.1	3.5±1.2	100.0±0.0	0.0	3002-79	44
RTQ	Figure 2	10/73	95.7±0.6	3.0±0.4	97.7±0.3	0.0	ETI-2-150	3164-28
RTQ	Figure 2	10/73	93.5±0.5	4.1±0.3	98.3±0.1	0.0	ETI-2-150	3164-20
RTQ	Figure 2	10/73	97.5±0.2	3.7±0.1	97.1±0.0	0.0	ETI-2-150	3164-5
DI	375°F/50 hrs	2/75	94.2±0.3	4.0±0.5	97.2±0.0	0.0	ETI-2-213	3380-15
DI	375°F/50 hrs	2/75	94.8±0.2	3.6±0.5	100.0±0.0	0.0	2-ETI-0275	3380-22
DI	375°F/50 hrs	2/75	93.5±0.5	2.6±0.3	100.0±0.00	0.0	3-ETI-0275	3380-18
DI	400°F/50 hrs	3/75	97.7±0.2	0.0	95.5±0.2	0.0	11-ETI-0375	3380-6
DI	400°F/50 hrs	3/75	90.3±0.2	0.0	95.6±0.2	0.0	10-ETI-0375	3380-16
DI	400°F/50 hrs	3/75	95.8±1.2	3.9±0.2	92.6±0.4	0.0	10-ETI-0375	3380-6
DI	425°F/50 hrs	3/75	76.8±2.0	1.1±0.1	53.1±3.0	0.1±0.0	11-ETI-0375	3380-12
DI	425°F/50 hrs	3/75	94.0±0.5	2.2±0.2	66.3±1.3	0.1±0.0	11-ETI-0375	3380-16
DI	425°F/50 hrs	3/75	95.5±0.2	2.7±0.1	70.0±2.0	0.2±0.1	12-ETI-0375	3380-8
DI	425°F/50 hrs	3/75	91.2±0.3	2.1±0.1	65.0±3.0	0.2±0.1	14-ETI-0375	3380-13
DI	425°F/50 hrs	3/75	89.0±1.0	2.3±0.1	47.1±5.0	0.2±0.2	12-ETI-0375	3380-22
DI	425°F/50 hrs	5/75	91.0±0.3	2.1±0.2	70.3±3.0	0.2±0.2	40-ETI-0575	3380-33
DI	425°F/50 hrs	3/75	92.8±0.3	3.0±0.2	78.1±1.0	0.2±0.2	12-ETI-0375	3380-17
DI	425°F/50 hrs	3/75	91.1±0.5	2.1±0.2	95.3±0.3	0.1±0.1	12-ETI-0375	3380-14

TABLE 10. EFFECT OF HEAT ON CHEMICAL COMPOSITION

TRANSFER LINES

AIRCRAFT	EXPLOSIVE (SHEATH)	AS RECEIVED	REPEAT THERMAL QUALIFICATON	AVERAGE CHEMICAL RESULTS % EXPLOSIVE BY WEIGHT					
				375°F/ 50 HRS	400°F/ 50 HRS	425°F/ 50 HRS	450°F/ 50 HRS	500°F/ 50 HRS	550°F/ 50 HRS
AH-1S	HNS-II/ HNBiB (silver)	98.6/0.1	97.8/0.0	99.8/0.0	87.9/0.1				
AH-1G	"	96.5/0.6	94.8/1.0	98.4/0.2	77.0/0.2	23.2/0.0			
F-14	"	100/0.0	97.7/0.9	99.1/0.9	94.6/0.0	68.2/0.2			
B-1	HNS-II/HNBiB (aluminum)	97.5/0.0	94.3/1.6	100/0.0	93.5/0.0	88.4/0.0			
F-111	DIPAM (silver)	98.4	98.6		99.4	98.3	100	5.4	0.1
F-15	"	96.5							

BOOSTER TIPS

AIRCRAFT	EXPLOSIVE (SHEATH)	AS RECEIVED	REPEAT THERMAL QUALIFICATON	375°F/ 50 HRS	400°F/ 50 HRS	425°F/ 50 HRS	450°F/ 50 HRS	500°F/ 50 HRS	550°F/ 50 HRS
AH-1S	HNS-I/ HNBiB (304 stainless steel)	96.2/3.2	97.0/3.4	96.3/1.8	91.2/2.9				
AH-1G	"	96.2/3.3	94.8/2.4	95.2/2.7	91.5/2.2	90.7/1.1			
F-14	"	98.6/0.8	93.5/2.9	93.4/3.3	91.0/1.6	90.2/2.2			
B-1	"	93.4/5.5	89.0/6.0	94.4/4.8	88.9/5.1	86.7/3.3			
F-111	"	97.5/2.5	97.7/1.8		91.0/2.3	79.1/1.4	74.8/0.9	22.0/0.0	1.3/0.0
F-15	"	98.4/0.7							

TABLE 11. CHEMICAL ANALYSIS OF EXPLOSIVE TRANSFER LINES

SAMPLE	NO. OF LINES/ UNITS TESTED	NO. OF YEARS IN SERVICE	AVERAGE CHEMICAL ANALYSIS RESULTS* BOOSTER TIP HNS-I/HNBiB	TRANSFER LINE HNS-II/HNBiB	DIPAM
RSRA	3	5.0	97.7/2.7	97.3/0.1	
F-15	3	6.0	98.4/0.7		96.5
F-111	4	4.0	99.0/2.2		99.3
AH-1S	2	4.7	96.2/3.2	98.6/0.1	
AH-1G	1	7.0	98.7/1.7	95.4/1.1	
B-1	1	3.0	94.0/4.9	97.0/9.9	
F-14	2	3.0	96.2/3.7	99.9/0.0	

*average weight percent

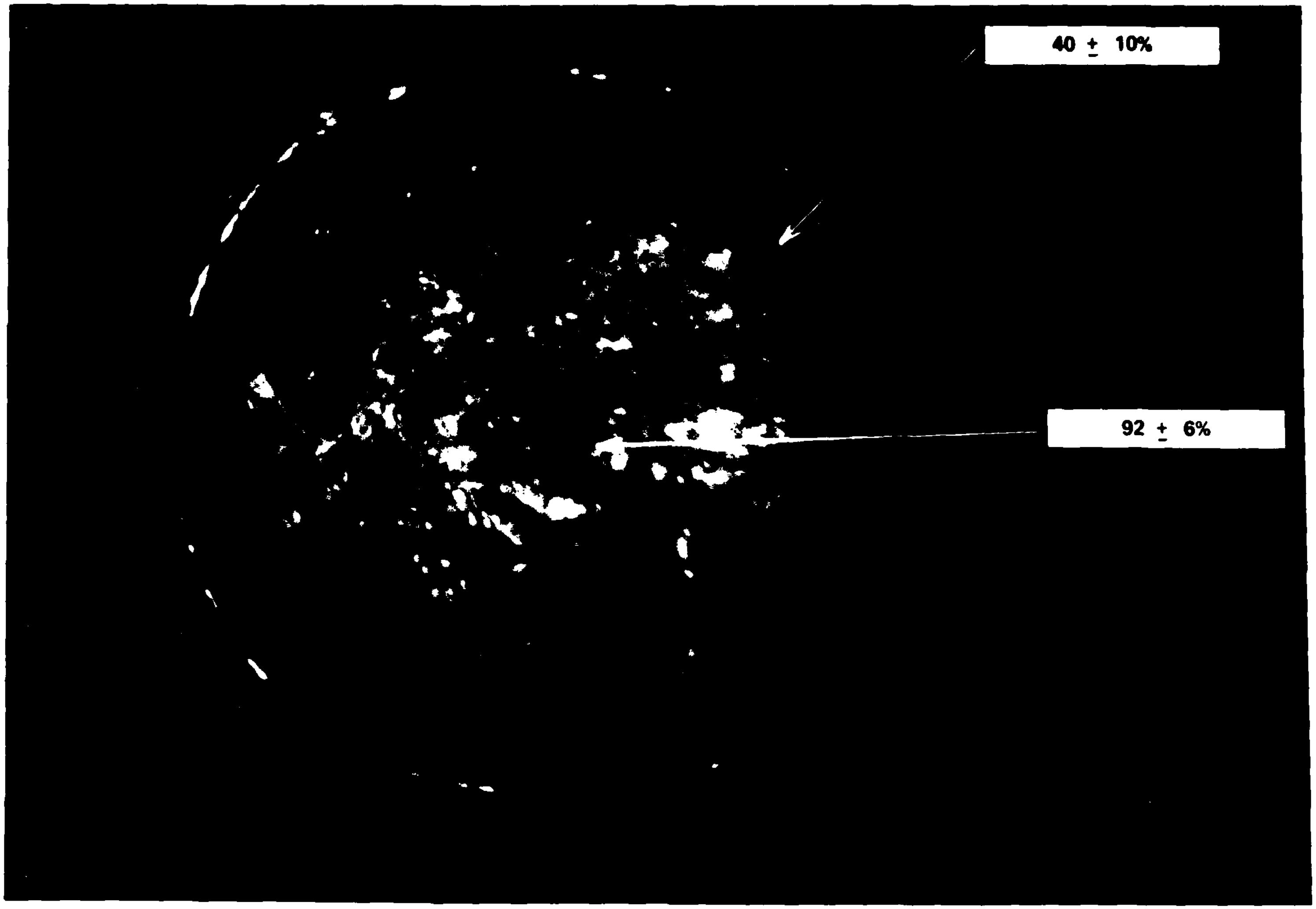


FIGURE 6. INTERNAL END VIEW OF A BOOSTER TIP REMOVED FROM A TRANSFER LINE EXPOSED TO 425° FOR 50 HR. PERCENTAGES ARE EXPLOSIVE REMAINING BY WEIGHT

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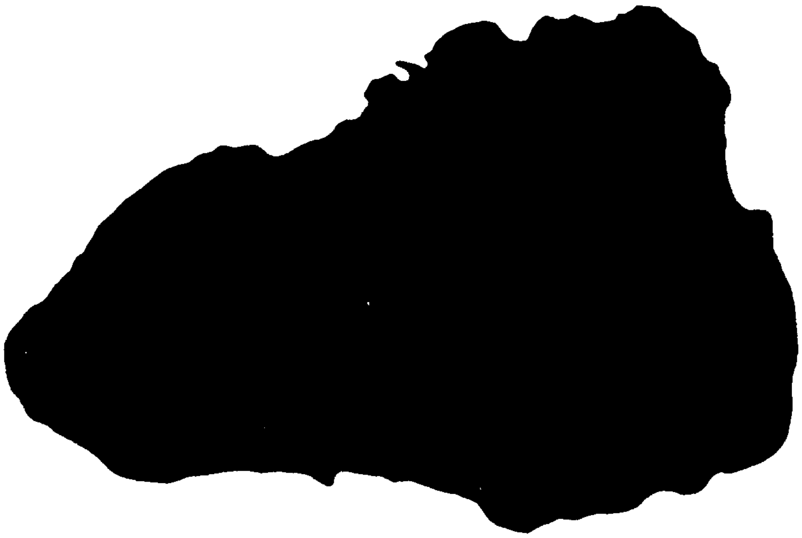

FIGURE 7. SIDE VIEW OF FERRULE CHARGE REMOVED FROM A TRANSFER LINE EXPOSED TO 500° F FOR 50 HRS (HNS-I WT % = 0.7-2.6 %)

FIGURE 8. SIDE VIEW OF FERRULE CHARGE REMOVED FROM A TRANSFER LINE EXPOSED TO 425° F FOR 50 HRS

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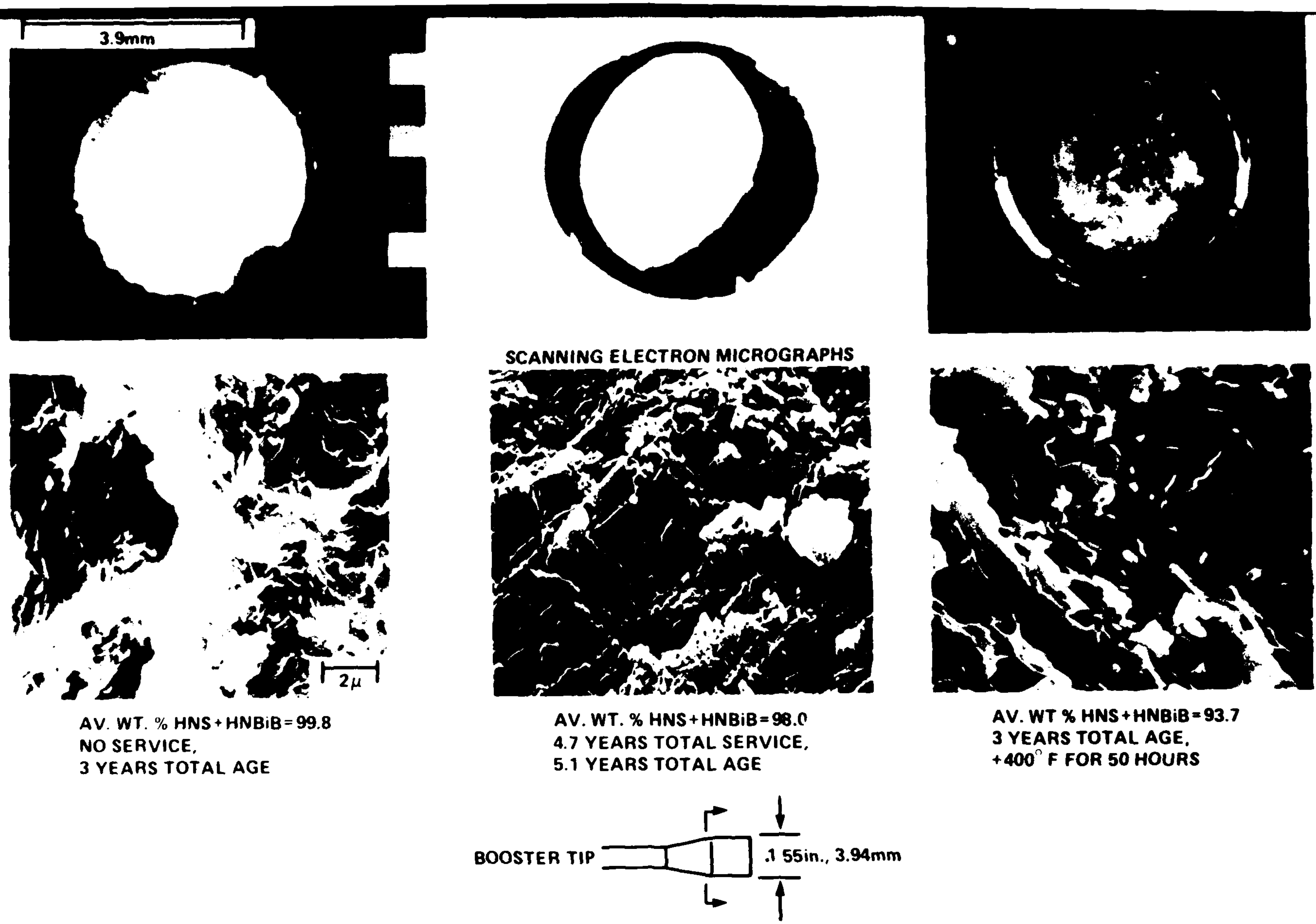

FIGURE 9. PHOTOGRAPHIC ANALYSES OF AH-1S BOOSTER TIP EXPLOSIVE

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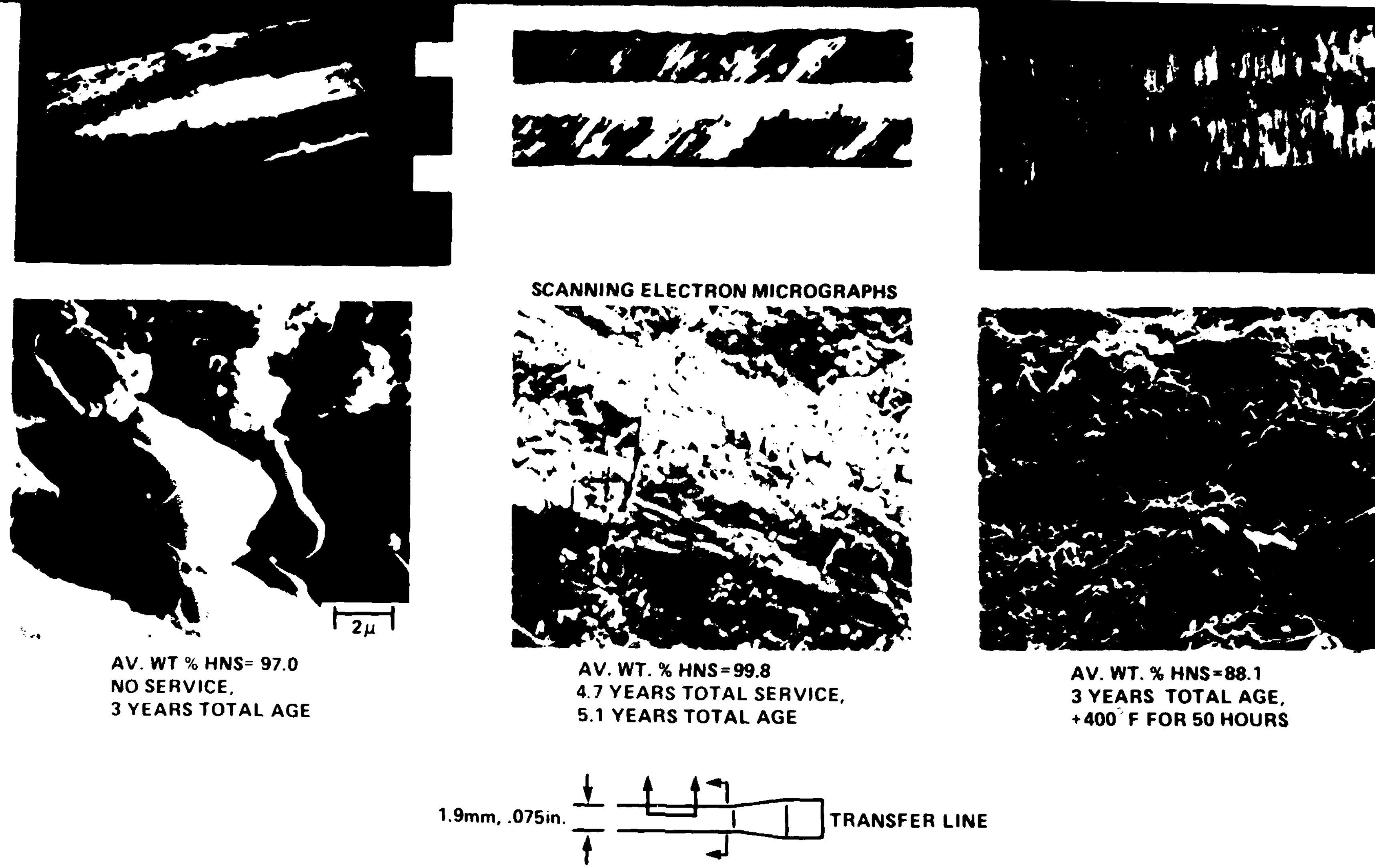

FIGURE 10. PHOTOGRAPHIC ANALYSES OF AH-1S TRANSFER LINE EXPLOSIVE

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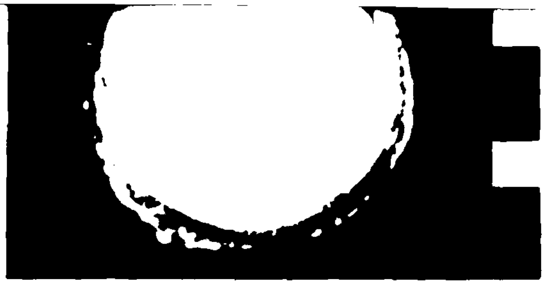
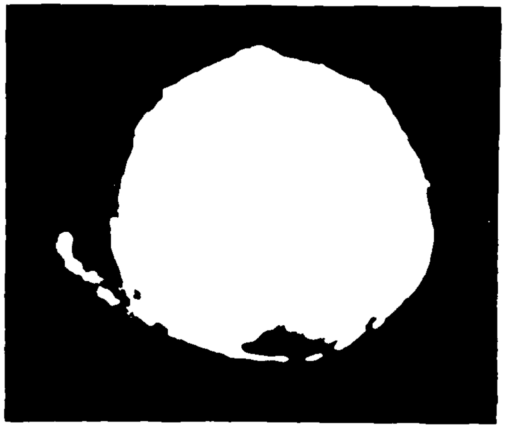
permit fully legible reproduction



AV WT % HNS + HNBiB - 98.6%

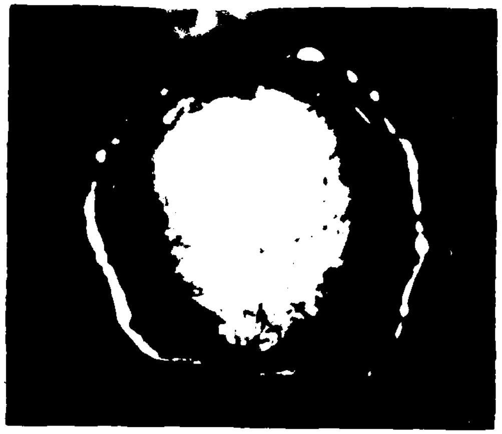
AV WT % HNS + HNBiB 95 7

S L AND +375 F FOR 50 HOURS



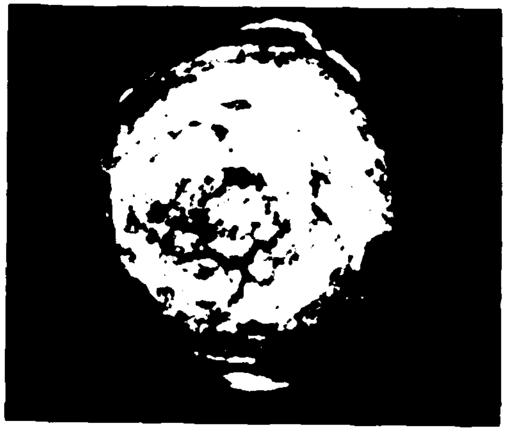
A. WT HNS + HNBiB 98 3

S L AND +400 F FOR 50 HOURS



AV WT % HNS + HNBiB 94.3%

S L AND +425 F FOR 50 HOURS



AV WT % HNS + HNBiB 91 8

BOOSTER TIP

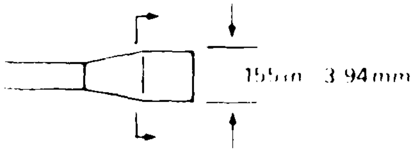


FIGURE 11. COLOR MACROPHOTOGRAPHS OF AH 1G BOOSTER TIP EXPLOSIVE ALL LINES ARE 9 YEARS OLD

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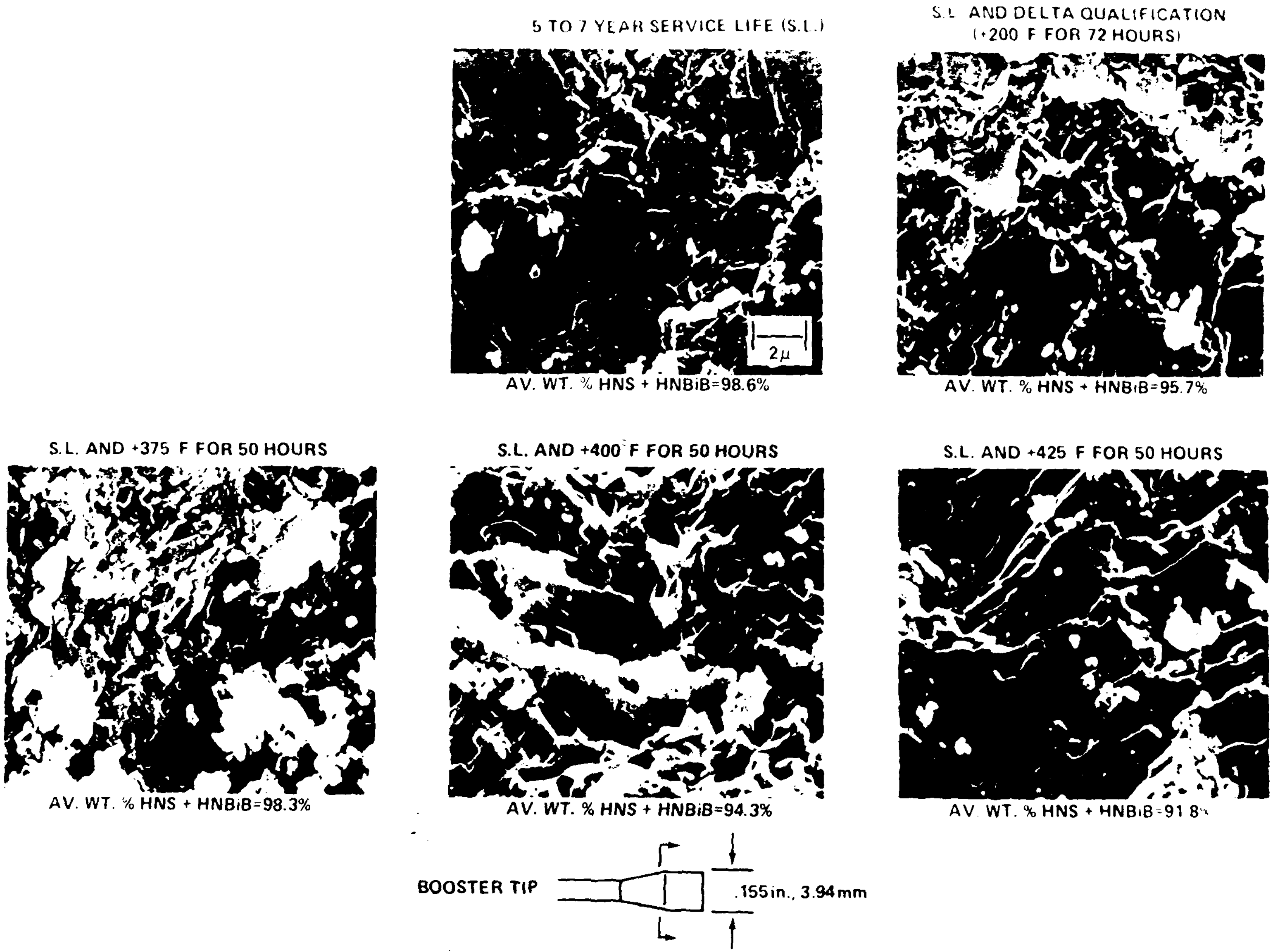

FIGURE 12. SCANNING ELECTRON MICROGRAPHS OF AH-1G BOOSTER TIP EXPLOSIVE; ALL LINES ARE 9 YEARS OLD

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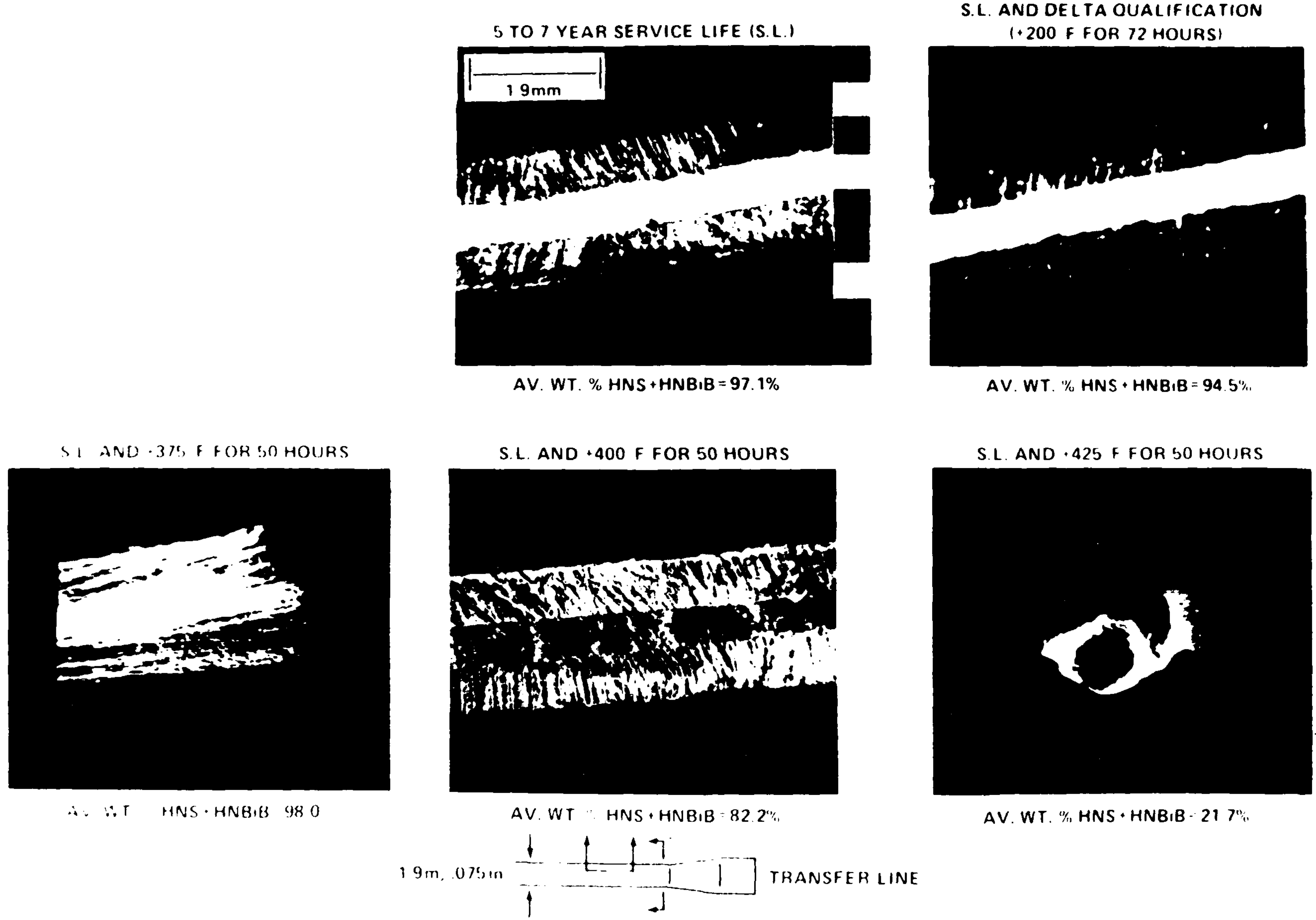

FIGURE 13. COLOR MACROPHOTOGRAPHS OF AH 1G TRANSFER LINE EXPLOSIVE. ALL LINES ARE 9 YEARS OLD

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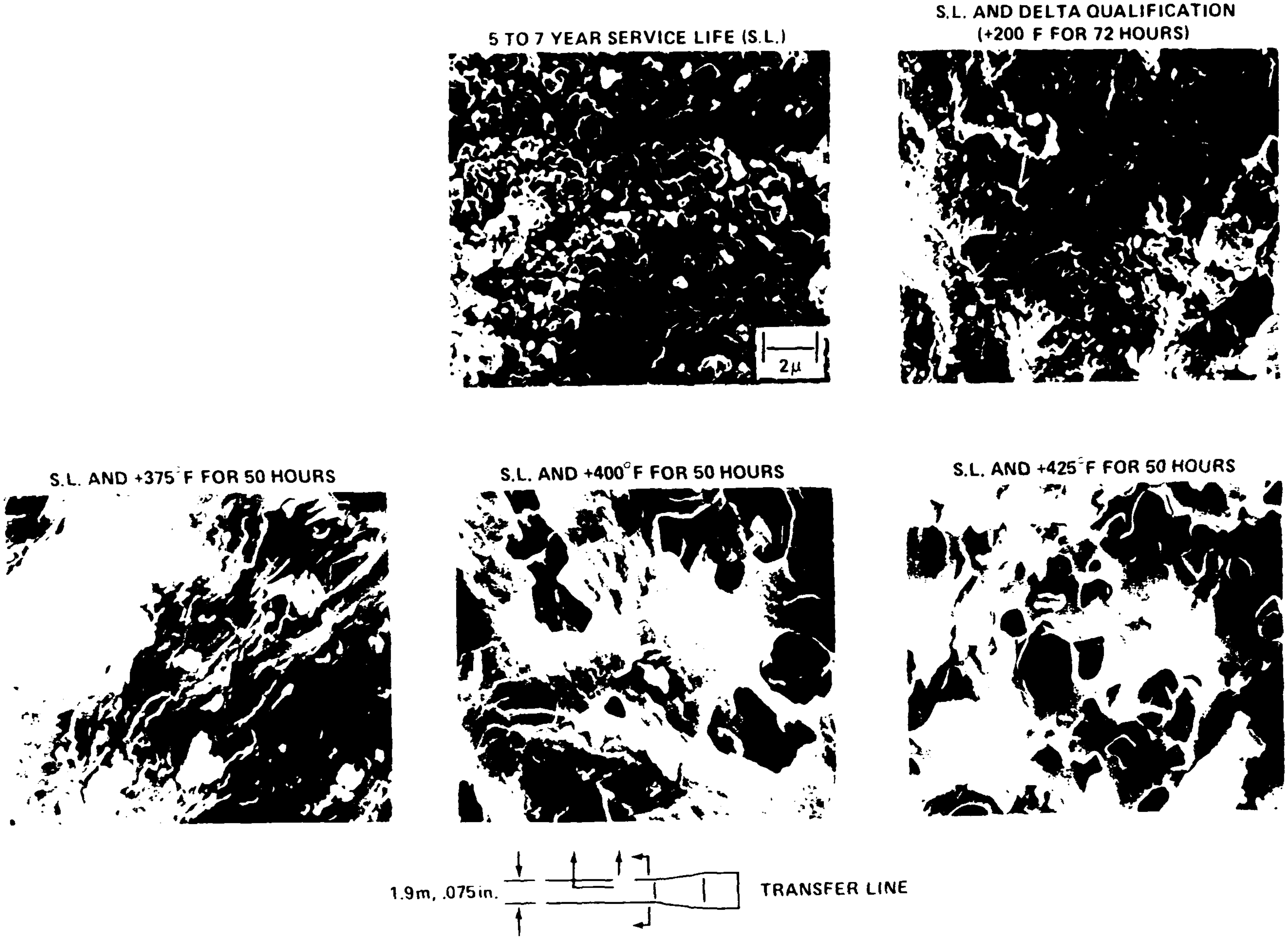

FIGURE 14. SCANNING ELECTRON MICROGRAPHS OF AH-1G TRANSFER LINE EXPLOSIVE; ALL LINES ARE 9 YEARS OLD

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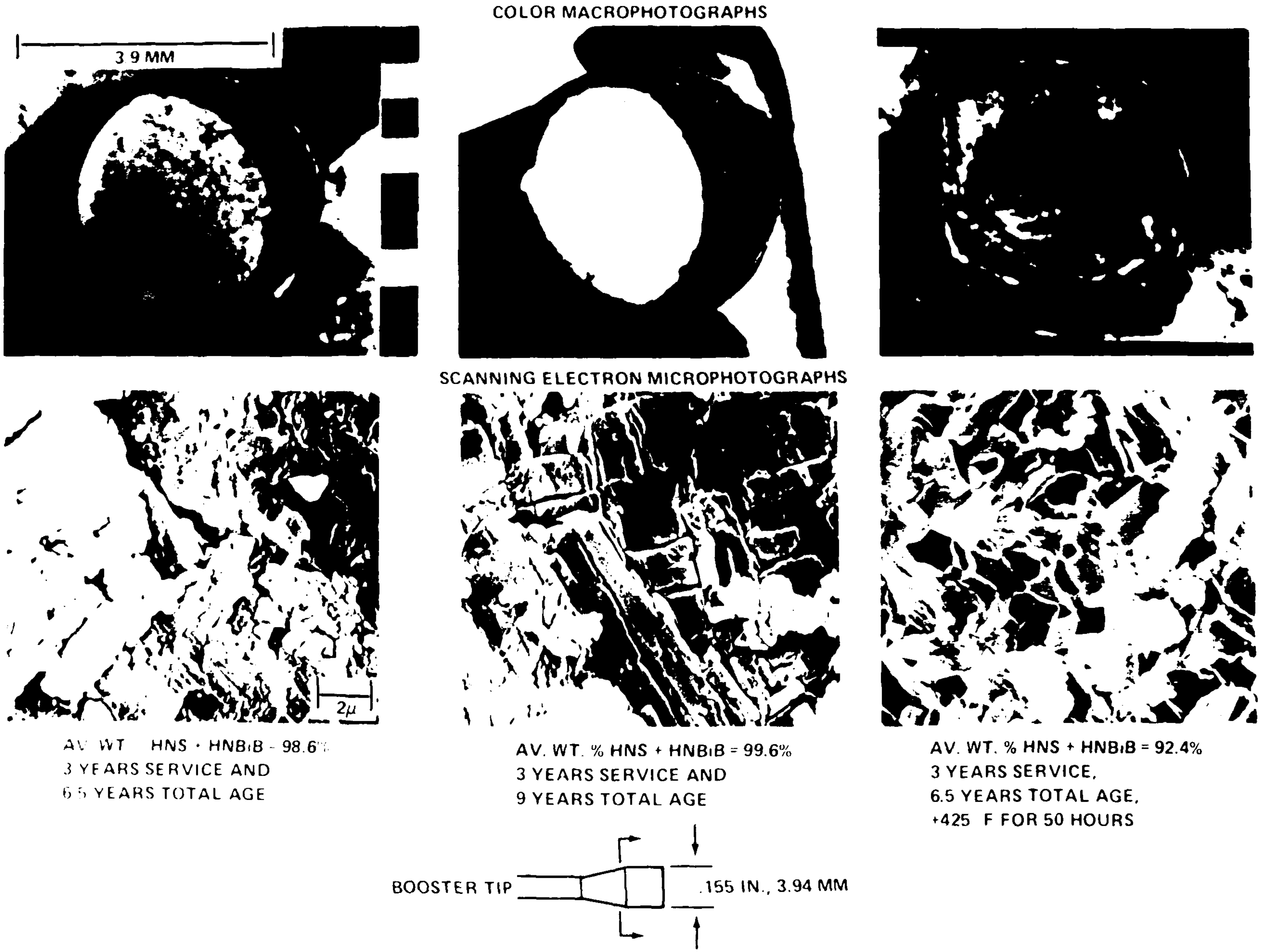

FIGURE 15. PHOTOGRAPHIC ANALYSES OF F-14 BOOSTER TIP EXPLOSIVE

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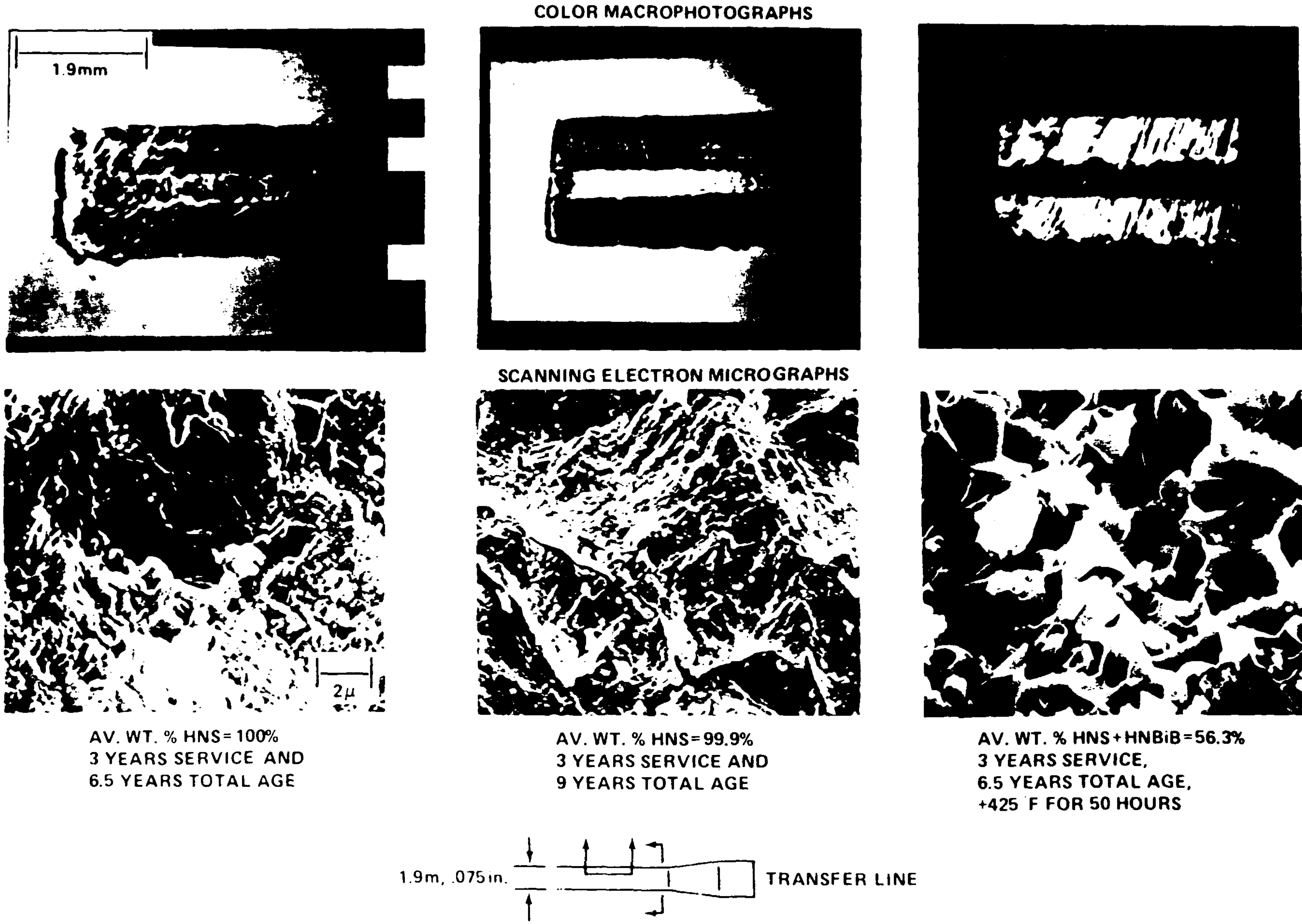

FIGURE 16. PHOTOGRAPHIC ANALYSES OF F-14 TRANSFER LINE EXPLOSIVE

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COLOR MACROPHOTOGRAPHS

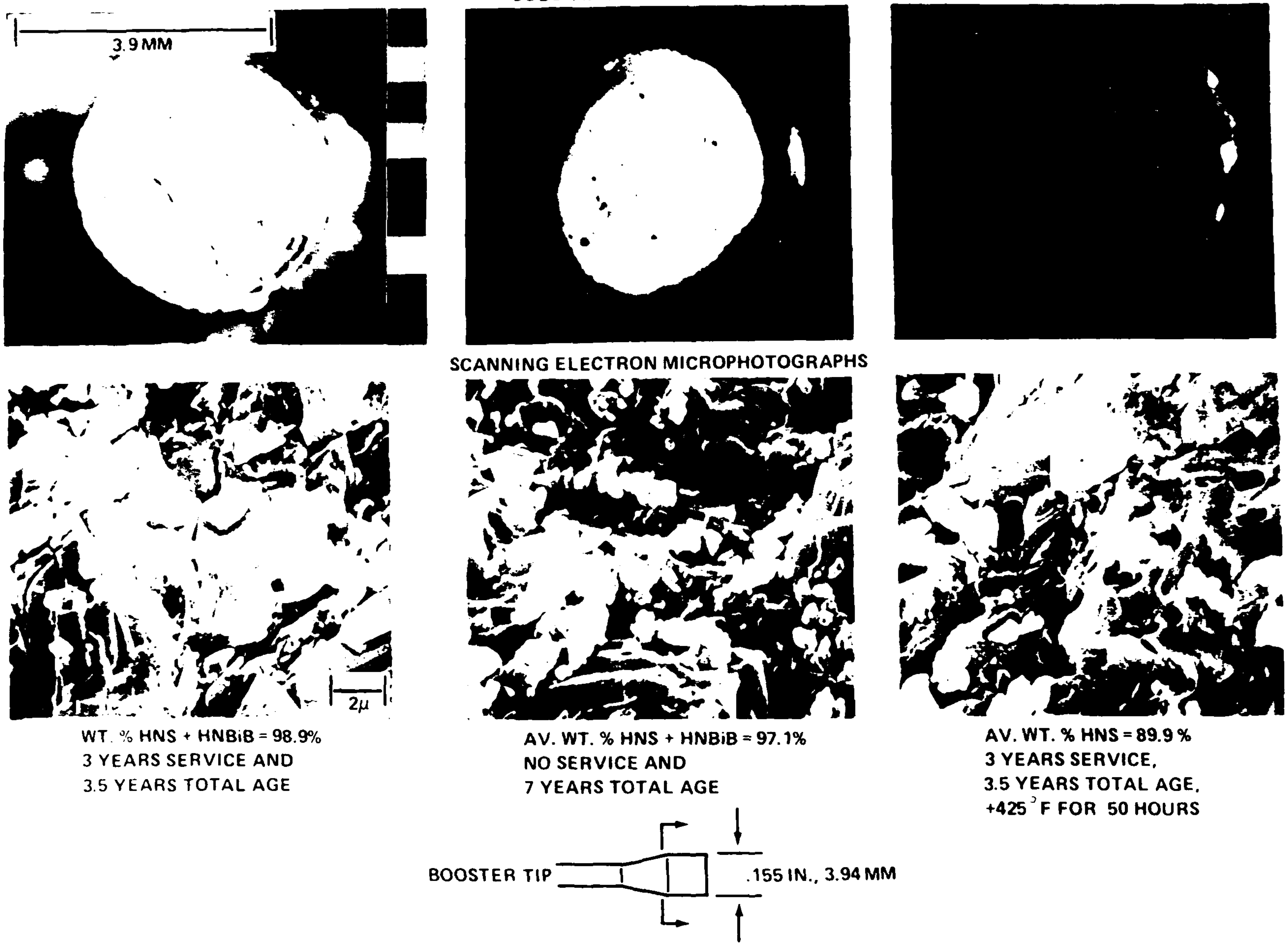

FIGURE 17. PHOTOGRAPHIC ANALYSES OF B-1 BOOSTER TIP EXPLOSIVE

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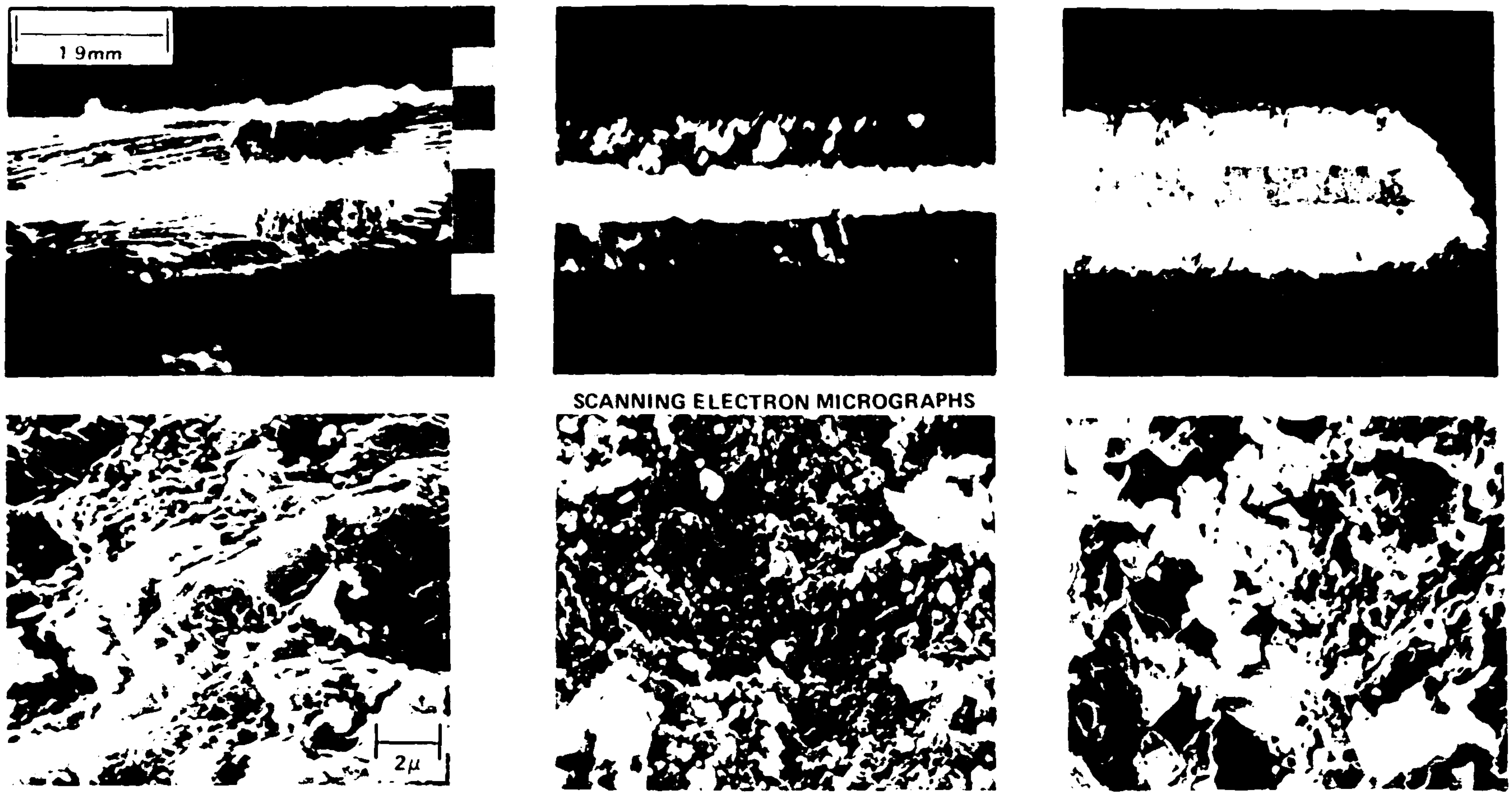
COLOR MACROPHOTOGRAPHS

SCANNING ELECTRON MICROGRAPHS



AV. WT. % HNS+HNBiB=97.0%
3 YEARS SERVICE AND
3.5 YEARS TOTAL AGE

AV. WT. % HNS+HNBiB= 95.7%
NO SERVICE AND
7 YEARS TOTAL AGE

AV. WT. % HNS=88.35%
3 YEARS SERVICE,
3.5 YEARS TOTAL AGE,
+425°F FOR 50 HOURS

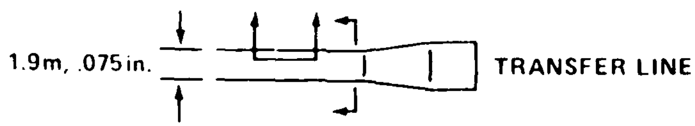


FIGURE 18. PHOTOGRAPHIC ANALYSES OF B-1 TRANSFER LINE EXPLOSIVE

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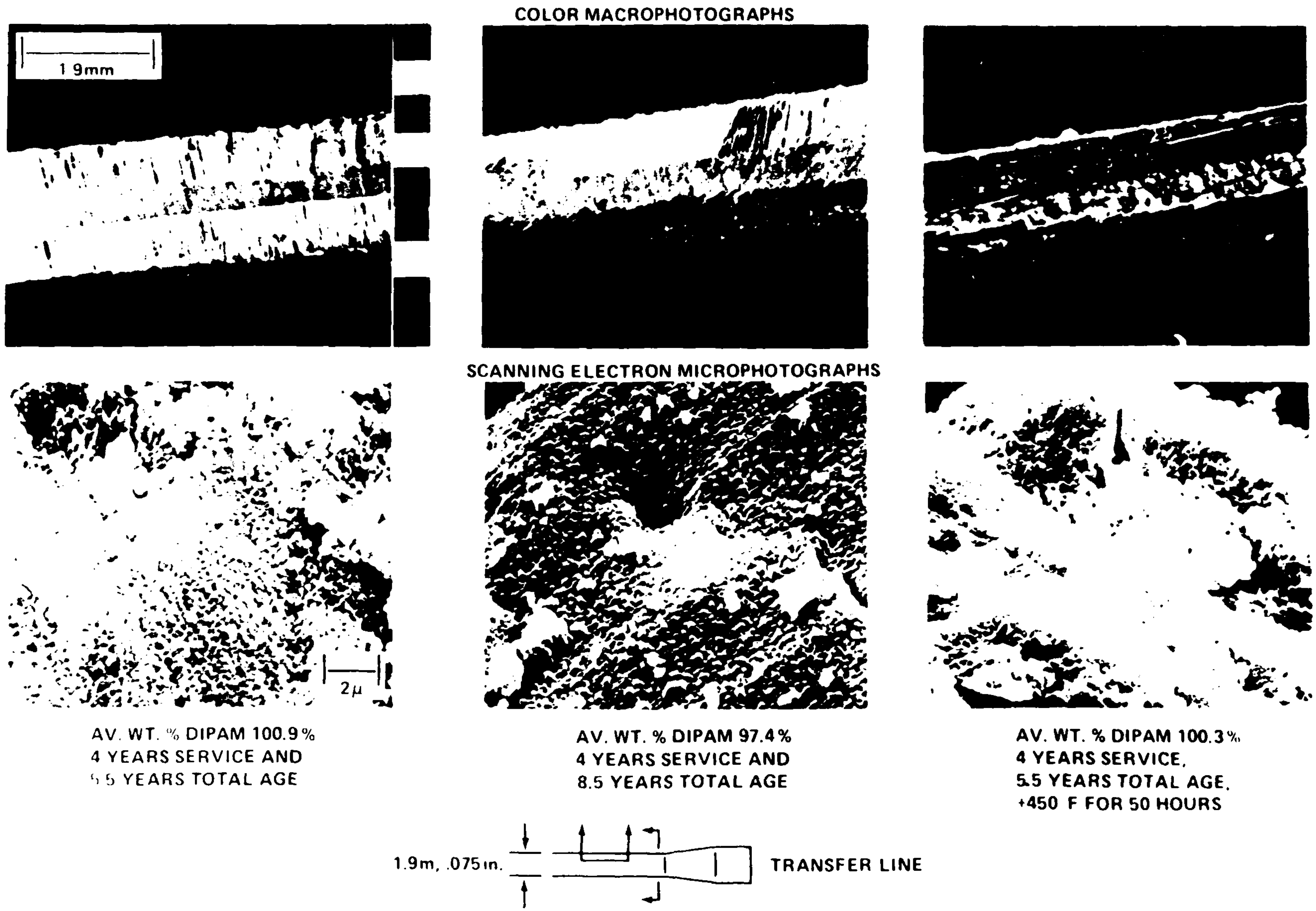

FIGURE 19. PHOTOGRAPHIC ANALYSES OF F-111 TRANSFER LINE EXPLOSIVE

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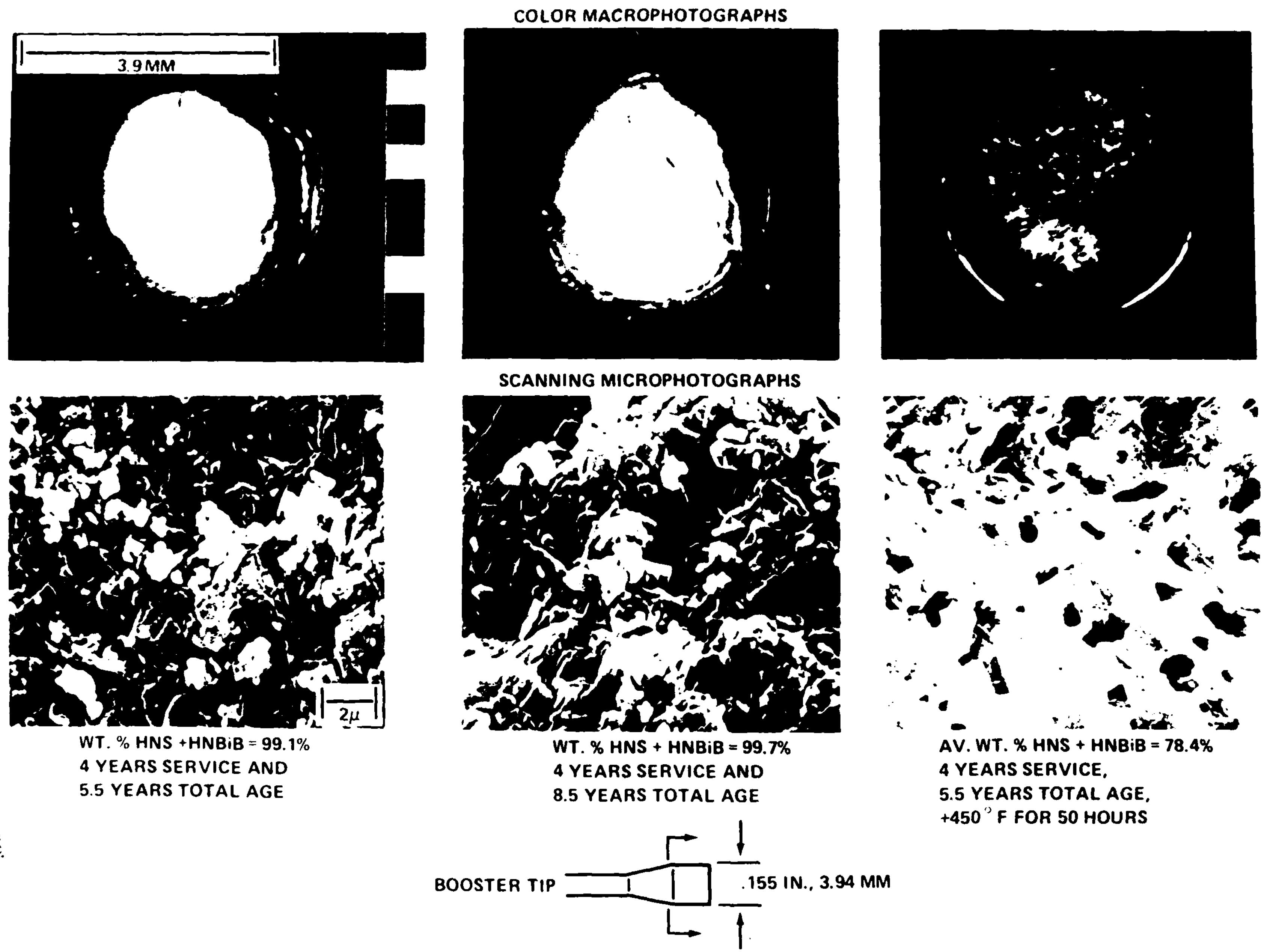

FIGURE 20. PHOTOGRAPHIC ANALYSES OF F-111 BOOSTER TIP EXPLOSIVE

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CONCLUSIONS

The effects of service, age, and thermal degradation were determined on transfer lines (used to initiate emergency escape systems) removed from the Army AH-1G and AH-1S, the Air Force B-1 and F-111, and the Navy F-14 aircraft. The results of this study indicate that the HNS and DIPAM explosive lines were not adversely affected by age (ambient storage from 1 to 10 years), service life (from 3 to 7 years) or a repeat thermal qualification cycle. These findings suggest that significant savings in the cost of (a) HNS and DIPAM rigid explosive transfer lines, (b) manhours needed for pyro change-out time, and (c) aircraft down-time can be realized for military and NASA aircraft by extending the service life of rigid explosive transfer lines. These data, when added to functional and nondestructive test results can be used to make responsible, conservative judgments concerning cord life extension.

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NOMENCLATURE

Al	Aluminum
Ag	Silver
BT	Booster tip
DI	Degradation investigation
DIPAM	Dipicramide
DMSO	Dimethylsulfoxide
ET	Explosive Technology
HNBiB	2,2',4,4',6,6'-hexanitrobibenzyl
HNS	2,2',4,4',6,6'-hexanitrostilbene
HPLC	High performance liquid chromatography
MDC	Mild detonating cord
on condition	SMDC lines remain in an aircraft and their condition verified by periodic sampling using the chemical, photographic, and functional tests established in this program[7]
PS	Performance standard, newest available
Pultrusion	Process in which a tube containing explosive is pulled through various fixed dies that reduce the tube diameter to the required dimensions
Pyro change-out	Removal and replacement of explosive components from aircraft
RSRA	NASA/Army rotor systems research aircraft
RTQ	Repeat thermal qualification
SEM	Scanning electron microphotograph
SL	Shelf life
SLD	Service life demonstration
SMDC	Shielded mild detonating cord
SOS	Space Ordnance Systems
Swage/Hammer with annealing	Process in which an explosive is press-loaded into a work-hardened tube. The tube is then moved through segmented dies and rapidly hammered to reduce the cross section. The die diameters are decreased during multiple passes until the desired explosive core load (grains/foot) are achieved. Three 218°C (425°F)-one hour heat cycles are used to anneal the work hardened tube during the process.

NOMENCLATURE (Cont.)

Swage/Hammer without annealing	Process in which fully annealed tubes are moved through segmented dies until the desired core loads are achieved.
TMc/S	Teledyne McCormick Selph

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